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VARIETAL IDENTIFICATION IN THE CAVENDISH GROUP OF BANANAS

By N. W. SIMMONDS

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Musa Cavendishii Lambert was described in 1837 from a greenhouse specimen and was named in honour of the owner of the plant, the Duke of Devonshire. It is a dwarf banana of very characteristic aspect which has attained great economic importance in various parts of the world. Studies of banana varieties made at the Imperial College of Tropical Agriculture showed, however, that it was connected by a series of intergrading mutant forms to bananas of more normal aspect and that the Latin binomial was invalid (Cheesman, 1933 ; Cheesman, Wardlaw and Spencer, 1933 ; Dodds and Simmonds, 1948). Cheesman named the assemblage of mutants the Cavendish Group and it is now evident that it is a complex of edible triploid cultivars of *Musa acuminata* (Dodds and Simmonds, 1948 ; Cheesman, 1948).

The problem of varietal identification in this group has been raised recently by the adoption in various West Indian islands of certain members of the group as export banana varieties to replace the Panama Disease-susceptible Gros Michel. It quickly became evident that varieties and names were confused in many places and that, even where mixed plantings were known to occur, identification in the field of the varieties concerned was very difficult. The situation prompted an investigation of problems of varietal identification in the group and the results are reported here.

A few technical terms need explanation. The banana is planted as a piece of rhizome (*bit*) or as a lateral shoot (*sucker*) from the parent ; shoots composed of tightly packed leaf sheaths (pseudostems) grow up and each ultimately bears an inflorescence in which the flowers are clustered at the nodes. The basal clusters are female and develop by vegetative parthenocarpy into *hands* of fruit, the individual fruits being the *fingers*. The number of hands in the fruit bunch thus depends on the number of female clusters in the inflorescence, and varies. In the banana trade the harvested bunch is referred to as a *stem*, the number of hands on the stem is the *grade*, and the term *bunch* has a special significance, i.e. a stem of nine hands. In this paper, however, the word " bunch " has been used in its more general and ordinary sense and preferred to " stem " as less liable to be misunderstood. The first bunch borne by a stool is the *plant* bunch ; subsequent ones are *ratoons* and the timing of their production is normally controlled by pruning of suckers ; as the female flowers develop into fruits, the distal portion of the inflorescence elongates and produces at successive nodes clusters of male flowers, each cluster subtended by a bract and one to three clusters exposed per day ; the male flowers and bracts are sometimes deciduous, sometimes persistent, and this is a character of considerable diagnostic value, though not of profound taxonomic significance.

Ten clones have been used as follows : Masak hijau from Malaya (Cheesman, Wardlaw and Spencer, 1933) ; Lacatan from Jamaica (Larter, 1938 : this is probably Bungulan rather than Lacatan of the Philippines). Hamakua from Hawaii (Pope, 1926) ; Highgrade from River Estate, Trinidad ; Robusta from Jamaica

(Larter, 1938); Congo from Surinam (Cheesman, 1933; Cheesman, Wardlaw and Spencer, 1933); Manaiula from Hawaii (but undoubtedly a wrong label—Pope, 1926); Poyo from Guadeloupe (Kervégant, 1935; Simmonds, 1952); Bongolore (provenance unknown); Giant Governor from Trinidad.

1. *Experiments in Trinidad.*

Three experiments were carried out at the Imperial College of Tropical Agriculture, Trinidad. They took the form of 4×4 Latin squares with one-plant plots. The ten varieties named above were used; the experiments were designed partly to identify the varieties and partly to gain information about diagnostic characters, attention being concentrated on vegetative characters for obvious practical reasons. All three trials were planted together in a small area of land shaded by *Gliricidia sepium*; no pruning was practised; observations were not carried on into the ratoons. Results are set forth in Table I.

TABLE I.

Measurements of banana varieties in three Latin square experiments at the I.C.T.A., Trinidad, B.W.I. Means and tests of significance of differences.

Character	Variety				Analysis*		
	1	2	3	4	1	2	3
	Masak hijau	Manaiula	Bongolore	Congo			
Height (dm.)† ..	37·5	26·5	28·0	26·8	43·2***	2·8	5·4
Petiole length (cm.)	50·3	41·2	39·0	37·8	9·1*	6·5	8·9
Leaf ratio‡	4·0	2·9	2·9	3·0	25·0***	0·37	6·7
Grade	6·0	7·0	7·5	7·4	3·5	—	10·8
	Hamakua	Congo	Robusta	G. Governor			
Height (dm.) ..	34·8	28·8	26·0	21·3	69·6***	2·7	4·9
Petiole length (cm.)	48·0	42·5	37·3	31·3	14·3**	7·5	9·5
Leaf ratio	3·7	2·9	2·8	2·4	32·8***	0·39	6·6
Grade	5·8	7·6	7·1	7·3	1·2	—	22·0
	Poyo	Masak hijau	Lacatan	Highgrade			
Height (dm.) ..	25·8	32·0	33·5	36·0	2·7	—	12·3
Petiole length (cm.)	38·3	46·8	50·3	53·0	4·1	—	13·5
Leaf ratio	2·9	3·6	3·5	3·7	7·8*	0·45	7·7
Grade	7·8	4·8	6·3	7·3	11·9**	1·33	11·8

NOTE. *—Analysis. No row or column item was significant. Column 1—Variance ratio for varieties ($n_1=3$, $n_2=6$), significance indicated by asterisks, thus: *—5 per cent.; **—1 per cent.; ***—0·1 per cent. Column 2—Least significant difference between varietal means at 5 per cent. level. Column 3—Coefficient of variation (standard error per cent. of general mean). †—Height from ground level to point of emergence of the bunch. ‡—Ratio of length to breadth of the second leaf before the bunch.

Leaf ratio, with its consistently low coefficient of variation, is evidently the most reliable diagnostic character; height of plant is apparently the next best. The classification of varieties suggested by these trials is obvious:

1. Plant short with a short petiole and low leaf ratio (2·4) : Giant Governor.
2. Plant of medium height, with intermediate petiole length and leaf ratio (2·8-3·0) : Robusta, Congo, Manaiula, Bongolore, Poyo.
3. Plant tall, with long petiole and high leaf ratio (3·5-4·0) : Masak hijau, Hamakua, Lacatan, Highgrade.

Thus it is clear that members of the Cavendish group can readily be identified or distinguished by means of experiment. The most pressing practical need, however, is for means of identification in non-experimental plantings and the next section approaches this problem. Attention is concentrated on varieties 2 and 3 for which the names Robusta and Lacatan respectively, currently used in Jamaica, may conveniently be adopted.

2. *The use of a discriminant function analysis.*

Thirty sets of data for each of Lacatan and Robusta were selected from a considerable mass of information relating to plantings of various ages and on various soils both in Trinidad and Jamaica. Selection was arbitrary and was intended to include a wide range of environmental variation in each variety. Leaf ratio, plant height and grade of bunch were analysed and the results are set out in Table II. Leaf ratio is, once again, the best single diagnostic character with a coefficient of variation of only 10·5 per cent. and some 12 per cent. misclassification. Plant height

TABLE II.

Discrimination between the Lacatan and Robusta banana varieties by single characters and discriminant functions.

Analysis of	Means (ranges)		Variance ratio (n_1, n_2)	Misclassification per cent.	Coefficient of variation per cent.
	Lacatan	Robusta			
L (Leaf ratio) ..	3·60 (2·8-4·7)	2·78 (2·3-3·1)	90·1 (1, 58)	12	10·5
H (Height, dm.) ..	32·2 (20-45)	24·9 (18-31)	26·2 (1, 58)	27	19·4
G (Grade)	6·13 (5-8)	7·17 (4-9)	13·7 (1, 58)	33	16·2
X_{LH}	+0·5522	+0·4264	53·8 (2, 57)	9	—
X_{LG}	+0·7158	+0·6212	40·4 (2, 57)	12	—
X_{HG}	+0·0414	−0·0009	18·1 (2, 57)	10	—
X_{LHG}	+0·5166	+0·3899	35·4 (3, 56)	9	—

Equations : $X_{LH} = 0{\cdot}1218\ L + 0{\cdot}003528\ H$
$X_{LG} = 0{\cdot}1510\ L + 0{\cdot}02809\ G$
$X_{HG} = 0{\cdot}003848\ H - 0{\cdot}01348\ G$
$X_{LHG} = 0{\cdot}1186\ L + 0{\cdot}003474\ H - 0{\cdot}003662\ G.$

and grade alone are of little use for diagnosis. Three, out of the four discriminants calculated, effect an improvement ; perhaps the most striking is that for height and grade which reduces misclassification to 10 per cent. from 27 per cent. and 33 per cent. respectively for its components. The function for leaf ratio and height is evidently the most useful and a graph can readily be constructed for work in the field.

By the use of leaf ratio alone, 10 per cent. of the sixty plants analysed would be misclassified ; all were Lacatan, which ranged down to 2·8. Robusta, by contrast,

TABLE III.

Measurements of two banana varieties in randomized block experiments in Jamaica, B.W.I. Means and tests of significance of differences.

	I. Bodles						II. Orange River		
	Lacatan		Robusta		t*		Lacatan	Robusta	t*
	Plant	Ratoon	Plant	Ratoon	Variety	Crop			
Height (dm.)†	26	34	23	29	6·06**	10·34**	20	18	4·42*
Basal circumference (cm.)‡ ..	71	84	70	86	—	10·41**	60	58	3·13*
Upper circumference (cm.)‡ ..	44	53	51	57	1·59	2·69*	38	43	2·45
Petiole length (cm.)	37	42	32	40	1·24	2·31*	26	23	2·25
Leaf size (sq. dm.)§	137	184	141	181	—	6·53**	109	115	—
Leaf ratio‖	3·5	3·6	2·8	3·0	6·02**	—	3·1	2·6	5·23**
Peduncle circumference (cm.) ..	22	23	24	25	4·00**	—	17	17	—
Age at shooting (10-day units) ..	28	—	25	—	—	—	41	39	—
Number of hands (Grade) ..	7·8	9·2	8·2	9·8	2·99*	8·98**	6·0	7·0	1·82

NOTES. * Significance of t indicated thus: *—5 per cent.; **—1 per cent.
† Height from base of pseudostem to point of emergence of bunch.
‡ Circumferences of pseudostem at ground and just below oldest green leaf.
§ Calculated from product of length × breadth of the second leaf before the bunch.
‖ Length/breadth of the second leaf before the bunch.

did not exceed 3·1 in this sample and has only once attained 3·2 in all these investigations. Hence to adopt the level 3·2 and upwards as diagnostic of Lacatan will occasionally lead to error for that variety but will very rarely lead to misclassification of a Robusta plant. The same six plants were misclassified when tested with the leaf ratio—height discriminant.

3. *Experiments in Jamaica.*

Two randomized block experiments were made in Jamaica ; one was on the low, fertile, irrigated St. Catherine plain at the Banana Breeding Station, Bodles, Old Harbour, and the other was on poor, hilly land, under natural rainfall, at Orange River Experiment Station, Highgate, St. Mary.

Table III shows that Lacatan is a taller plant than Robusta and that it has relatively narrower leaves. These are the most pronounced differences, but there are also indications that it has, at least in some environments, a more tapering pseudostem, a slightly longer petiole, a more slender peduncle, slower maturity and a smaller bunch. These results agree well enough with general field knowledge, and, indeed, it was its short and sturdy aspect that gave the Robusta banana its name in Jamaica. It will be noticed that, in the Bodles experiment, there was a general increase in the size of the plant and its various parts as between plant and ratoon crops ; this is normal experience with all bananas, but it is important for the present purpose that differences between crops in any one character usually greatly exceeded differences between the two varieties. A good diagnostic character should be at once pronounced, easily observed and but little variable with crop. Leaf ratio is evidently the most useful character listed in Table III and this agrees with the conclusion drawn from the Trinidad experiments and discriminant function analysis described above.

4. *Certain other bananas.*

In Table IV are summarized measurements of five members of the Cavendish group of bananas. Observations were made in variety collections and miscellaneous plantings in Trinidad and Jamaica. The five varieties form a graded sequence of increasing stature, petiole length and leaf ratio. There are also differences in the behaviour of the bracts of the male rachis, those of the Extra Dwarf and Dwarf Cavendish being persistent, those of the Giant Cavendish somewhat (rather variably) so and those of Robusta and Lacatan completely deciduous. The five varieties

TABLE IV.

Measurements of five members of the Cavendish group of bananas. Based on miscellaneous plantings in Trinidad and Jamaica, B.W.I.

Character	Extra Dwarf	Dwarf	Giant	Robusta	Lacatan
Height (dm.)	7·1	15·3	19·4	23·0	30·4
Petiole length (cm.) ..	9·0	21·8	30·1	38·2	42·8
Leaf ratio	1·63	1·99	2·37	2·79	3·58
Range of leaf ratio ..	1·6-1·7	1·8-2·2	2·1-2·6	2·3-3·1	3·0-4·7
Grade of bunch ..	6·00	6·63	7·59	6·46	6·02

evidently differ principally in the elongation of leaf structures during development and, though the data of Table IV refer only to mature flowering plants, varietal differences are apparent at a very early stage in growth, long before flowering. Thus measurements of leaves of young plants of Lacatan and Robusta showed that the leaf ratio rose through development but that, when allowance was made for stage of development by the use of leaf area as a co-variate, the two varieties were distinct from the beginning of growth. Diagnosis of variety by the leaf ratio of immature plants would, however, be extremely difficult because of the change in leaf ratio with development. There are also differences in fruit size between the members of the complex. Neglecting the Extra Dwarf Cavendish, which is slow growing and weakly, there is a general increase in fruit size along the series from the Dwarf Cavendish to Lacatan. Thus declining grades are to some extent compensated for by increased fruit size ; experimentation alone could reveal the exact relationships involved.

There probably exists also in the Cavendish Group a number of mutants which differ from their parental forms in characters other than those of stature and leaf shape described above. Thus dichotomy of the growing point, leaf variegation, a deciduous hairiness and minor differences of habit have all been described (Cheesman, 1933 ; Kervégant, 1935 ; Chevalier, 1935) ; probably many more would be revealed by careful search.

Mutants analogous to those known in the Cavendish group occur in other banana varieties and two examples are worth giving. First, the Gros Michel banana has produced a number of mutants in Jamaica of which one at least differs in stature of the plant (Larter, 1934) ; the Highgate banana (Table V) is a shorter and sturdier

TABLE V.

Measurements of two pairs of banana varieties.

Character	Rajapuri*	Nendra padaththi*	Highgate†	Gros Michel†
Height (dm.)	22·1	33·1	27·7	31·8
Petiole (cm.)	40·0	52·8	44·1	54·1
Leaf ratio	2·39	3·33	2·28	3·23
Range of leaf ratio ..	2·2-2·5	3·0-4·2	2·2-2·5	3·1-3·4
Grade	7·86	6·69	10·40	9·25

NOTES. * Data from the I.C.T.A. and River Estate, Trinidad.
† Data from the Banana Breeding Station, Bodles, Jamaica.

plant than the Gros Michel and bears a larger bunch (though the individual fruits are somewhat smaller). Evidently Highgate is to Gros Michel what Robusta is to Lacatan and the variety has found a certain amount of agricultural favour in Jamaica by reason of its good grade and its stocky and wind-resistant habit ; it is, however, as susceptible to Panama Disease and Cercospora Leaf Spot as Gros Michel (Larter, 1936).

The second example concerns two Indian banana varieties which came to the I.C.T.A. collections separately in 1934. One, a tall variety, Nendra padaththi

(Introduction no. 149), came from Madras, the other, a short type, Rajapuri (Introduction no. 158), from Bombay. Both were recognized as *acuminata-balbisiana* hybrid triploid types (cf. Dodds and Simmonds, 1948) and recent detailed taxonomic studies have failed to reveal any point of difference between them, except as shown in Table V. It seems plausible to infer that one is a mutant of the other, despite the superficial differences between them.

CONCLUSIONS AND SUMMARY.

The Cavendish group contains at least four mutants of economic importance—the Dwarf Cavendish, Giant Cavendish, Robusta and Lacatan. These varieties differ from each other in stature, leaf ratio, grade, rate of maturity, fruit size, etc. Persistence of bracts on the male rachis serves to distinguish the first two from the last two ; within each pair, leaf ratio is the best diagnostic character though not an infallible one. A slight improvement in discrimination may be effected by means of a discriminant function for leaf ratio and height. Thus in a mixed planting most (but not all) plants may confidently be assigned to one variety or another.

Analogous mutants occur in other bananas and it seems likely that somatic mutation has provided an important source of variability in this crop (cf. Baker and Simmonds, 1951) as in others (e.g. potatoes, Davidson and Lawley, 1953 ; pineapples, Collins and Kerns, 1938 ; sugar cane, Mangelsdorf, personal communication ; and various fruit trees, Shamel and Pomeroy, 1936).

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STEAM PRESSURE IN SOIL STERILIZATION

I. IN BINS

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For many years growers, as it suited their circumstances or fancy, have used high or low pressure steam for the partial sterilization of potting soil, and apparently there is some confusion as to the importance and function of steam pressure. Although much work has been done on chemical changes in the soil following sterilization, few attempts have been made to compare with any precision the working efficiency of high and low pressure steam. From theoretical considerations it seemed that pressures of the order commonly quoted are unnecessarily high and uneconomic. Investigations were planned, therefore, to obtain precise information, under full-scale practical conditions, on the various factors pertaining to the steam sterilizing of soils. This account deals with the sterilization of soil in bins.

An example of a low pressure bin sterilizer is the John Innes low pressure sterilizer. This consists of a furnace and water tank over which is a perforated plate which allows the steam, at little more than atmospheric pressure, to pass up into the soil. This sterilizer has a capacity of $\frac{1}{2}$ cu. yd. and takes 30-45 minutes to reach sterilizing temperature. It can be built by the nurseryman at a low capital cost. A typical high pressure outfit comprises a vertical boiler having a capacity of 450 lb. steam per hour with a working pressure of 80 lb. per sq. in. The steam is conveyed to one or more sterilizing bins by a 1-$1\frac{1}{4}$ in. diameter pipe and about 15 minutes is required to bring the soil to sterilizing temperature. Whilst high pressure sterilization is quicker than low, a much larger capital outlay is required. Full descriptions of both these systems have already been published (2), (3).

Methods.

Apparatus.

Steam for the experiments was supplied by a Robey No. 24 locomotive type boiler, having a maker's rated capacity of 1,500 lb. steam per hour and a maximum pressure of 120 lb. per sq. in. The boiler was oil-fired and steam pressure automatically controlled by a pressure-stat. Steam volume was measured by a Kent 3-in. RS/C flowmeter fitted as close to the boiler as steam flow requirements permitted.

It was found that by making slight adjustments to the pressure-stat the pressure at the meter could be controlled to ± 1 lb. per sq. in., a necessary measure if steam volume is to be ascertained with any accuracy. Steam pressure at the boiler, the meter, the end of the steam main and in the sterilizing grid was measured by Bourdon type pressure gauges and also, in the case of pressures below 5 lb. per sq. in. at the grid, by a manometer. A permanent underground 3-in. steam main, lagged with corrugated asbestos, conveyed the steam from the boiler house to a pair of John Innes medium pressure sterilizing bins 40 yards distant. These bins are joined to the steam main by 3 ft. of $1\frac{1}{4}$-in. flexible pipe. Each sterilizing bin (2) is 5 ft. $2\frac{1}{2}$ in.

square, having two brick sides and two removable wooden ends. A pipe grid, made from two parallel $1\frac{1}{4}$-in. headers joined by seven $\frac{3}{4}$-in. pipes having $\frac{1}{8}$-in. orifices drilled in the top to allow the steam to pass into the soil, is countersunk into the concrete base of the bin. When filled to a depth of 12 in., each bin has a capacity of 1 cu. yd.

Loam.

The loam used was a medium clay loam suitable for compost making, and had been standardized in the stack in the recommended manner for making John Innes composts. It was shredded and mixed to ensure homogeneity of texture and moisture content. After shredding it had a particle size similar to that obtained by using a $\frac{3}{8}$-in. sieve. Moisture content is expressed as percentage of oven dry weight. The weight of steam used for each test was the amount taken to raise the initial soil temperature from 54° F. (12° C.) to a minimum of 180° F. (82° C.) and the time taken is referred to as the steaming period. Sterilization was considered satisfactory when a temperature of 180°-212° F. had been maintained for 10 minutes. As the heat loss from the soil was very small, it was not necessary to continue to pass steam when once the temperature of the whole of the soil had been raised to the minimum of 180° F. The steam was then turned off, and sterilization completed by the residual heat of the soil.

When steam is used with consequent rapid heating, the bulk of the soil is necessarily heated to 212° F. It frequently, however, happens that some parts of the bin are slower to heat up than others and these parts, termed " cold spots ", develop even when the loam has been well mixed before filling the bin. Cold spots are often due to small differences in compaction of the loam.

Experimental.

The effect of boiler pressure and grid orifice spacing.

Grids with $\frac{1}{8}$-in. orifices spaced at 9 in. and $4\frac{1}{2}$ in. respectively, were first compared in the two bins with meter pressures ranging from 5-40 lb. per sq. in. (Tests 1-10, Table I.)

As pointed out above, high pressure steam systems in practice give quicker heating than do low pressure systems, and it is widely assumed that the higher pressure, by giving more rapid penetration, plays an important part. Consequently, high pressure boilers are often deemed essential for rapid heating. Table I shows the relationship between boiler pressure and length of heating period for both grids. In addition, it shows the increased rates of steam production at the higher boiler pressures. That pressure alone at either the boiler or the grid cannot be taken as the criterion of the heating period is shown by the following comparisons. Tests 3 and 9 were made with the 9-in. and $4\frac{1}{2}$-in. grids respectively, the boiler pressure being 24 lb. per sq. in. in both cases. Although pressure in the 9-in. grid was approximately twice that in the $4\frac{1}{2}$-in., the soil in the former required 40 per cent. longer time to heat up. In Tests 5 and 10, again with 9-in. and $4\frac{1}{2}$-in. grids, there was no significant difference in the heating periods, but both the grid and boiler pressures were approximately 15 lb. per sq. in. higher with the 9-in. grid.

It is clear that whilst there is no apparent connection between pressure and length of the heating period for the two grids, there is a direct relationship between

TABLE I.

Results of steaming loam with three grids at various boiler pressures.

Grid orifice spacing	Test no.	Steam pressure (lb./sq. in.)				Time (min.)	Boiler evaporation (lb./hr.)	Steam (lb./cu. ft.)	Moisture content of loam %			lb. water increase (per cu. ft.)*	Steam flow (lb./cu. ft./min.)
		Meter	Boiler	End of main	Grid				Before	After	Difference		
9 in.	1	5	7	4·5	1·7	34	319	6·70	18·70	22·30	3·60	1·94	0·197
	2	10	12	8·0	3·6	23	490	6·95	25·95	29·80	3·85	2·08	0·302
	3	20	24	19·0	8·5	14	781	6·75	28·15	33·78	5·63	3·04	0·482
	4	30	36	28·0	15·0	10	1,007	6·22	29·14	33·84	4·70	2·54	0·622
	5	40	44	27·0	20·0	7	1,261	5·45	26·74	30·94	4·20	2·27	0·778
$4\frac{1}{2}$ in.	6	5	8	4·5	1·0	34	350	7·35	30·90	35·05	4·15	2·24	0·216
	7	10	12	9·0	1·7	19	592	6·95	30·30	35·75	5·45	2·94	0·366
	8	15	20	13·0	2·7	14	738	6·38	29·20	34·80	5·60	3·02	0·456
	9	20	24	18·0	3·9	10	986	6·09	31·40	36·90	5·50	2·97	0·609
	10	25	30	23·0	5·5	8	1,093	5·40	31·89	36·70	4·81	2·59	0·675
$2\frac{1}{4}$ in.	11	5	7	4·5	1·0	39	351	8·45	26·40	30·5†	4·03†	2·18	0·217
	12	15	19	13·5	1·4	13	773	6·21	26·60				0·478
	13	25	29	23·0	2·1	8	1,170	5·78	26·40				0·723

* 1 cubic foot of prepared oven dry loam weighs 54 lb.
† after 24 hours.

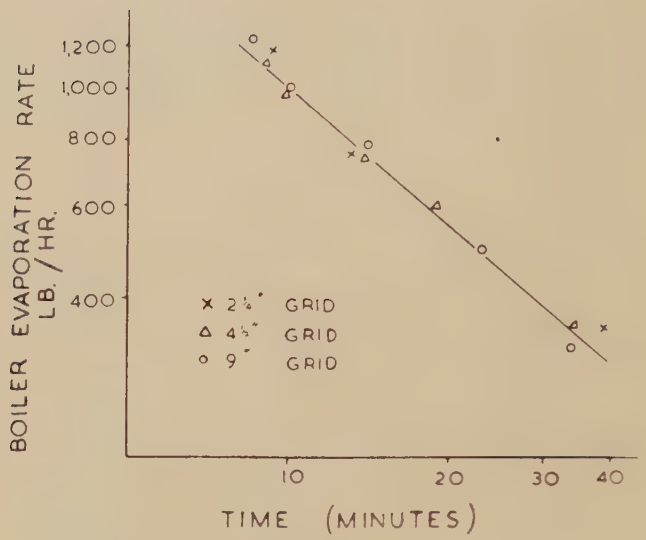

Fig. 1.
Relation of steaming time to boiler evaporation rate.

the heating period and the boiler rate of evaporation (Fig. 1). If equal heating efficiency is assumed, quantity of steam alone, not pressure, is the determining factor. Pressure is important only in so far as most pipe systems are of insufficient size to carry large quantities of low pressure steam to the bins. Fig. 2 gives the increased

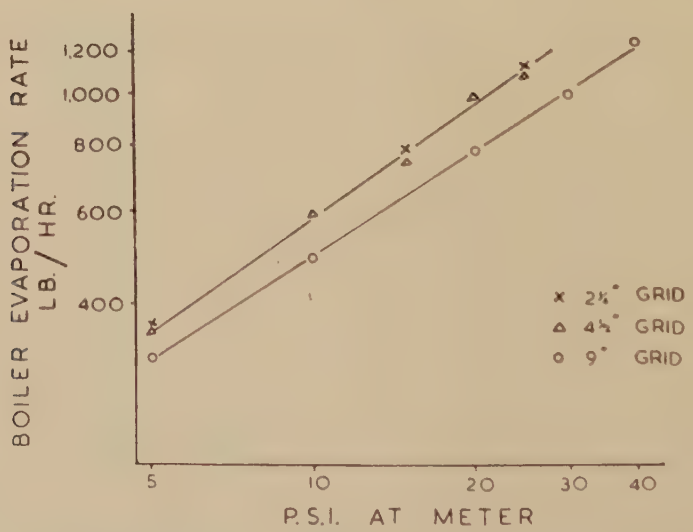

Fig. 2.
Effect of grid orifice spacing on rate of boiler evaporation.

rate of boiler evaporation when using the $4\frac{1}{2}$-in. grid. Meter pressure was chosen in preference to boiler pressure, as meter pressure could be read with greater accuracy.

Thus, within the limits of the above experiments, the main effect of increasing the number of orifices can be stated in two ways :

(*a*) When steam is produced at a given rate the working pressure of both boiler and grid is lowered.

(*b*) Boiler evaporation rate is increased at any given boiler pressure.

The effect of orifice spacings at $2\frac{1}{4}$ in. was also studied and it will be noticed (Fig. 2) that, compared with the $4\frac{1}{2}$-in. spacing, there was no significant difference in boiler rate of evaporation and steaming period, indicating that the limiting factor, which previously had been the total orifice area, was now probably either the short length of $1\frac{1}{4}$-in. pipe joining the steam main to the grids, or the steam valve.

Steam required per cu. ft. of loam.

With the exception of Test 1, there is a decrease in the amount of steam required per cu. ft. of loam as the steaming period is shortened (Fig. 3). This cannot be attributed either to boiler or to grid pressure alone, but is closely related to the

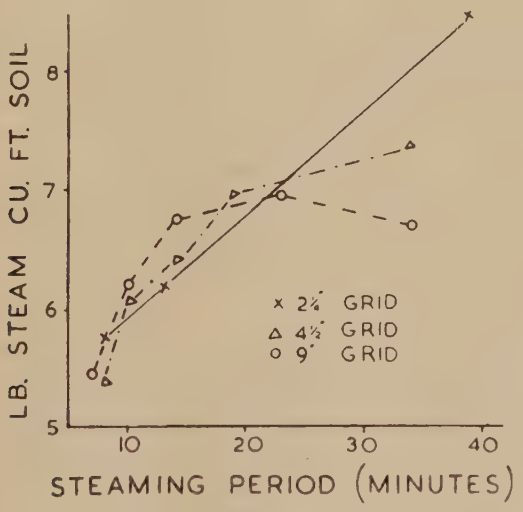

Fig. 3.

Relation of quantity of steam to steaming period.

boiler rate of evaporation. The increase in steam requirement for long steaming periods arises from two main factors. First, the wooden boards at the ends of the bin do not make steam-tight joints at the base and some steam spreads out under the boards and is lost. Second, slow rates of steaming often result in uneven heating of the soil, because the sides of the bin heat up before the centre. Once the heat has reached the surface of the soil there is a large steam loss from the heated parts, even when the soil is covered with hessian. It was also observed when working with the $2\frac{1}{4}$-in. grid, that steam loss was greater than with the $4\frac{1}{2}$-in. grid. This

was due to the end orifice in each pipe being nearer to the boards, thereby increasing the leakage. When the end orifices were closed, this loss was reduced. The smaller quantity of steam used in Test 1 can be accounted for by the lower moisture content of the loam.

Moisture content of soil.

An objection sometimes raised against the use of low pressure steam is that it renders the soil much wetter than does high pressure steam. It was found, however, that the increase in moisture content was similar with both systems. The most important points to observe with regard to producing steamed soil in a usable condition are :

(*a*) The initial moisture content of the soil should be just under " potting condition ", i.e. 25-30 per cent. for a medium clay loam.

(*b*) The grid and the main supply pipe should be drained of all condensed steam from previous use.

(*c*) The steam should be as dry as possible, (i) by keeping the main short, (ii) by the use of lagging, and (iii) by fitting a steam drier or separator at the end of the main to remove free moisture.

The moisture content figures following steaming, Table I, were obtained from samples taken immediately after steaming as the loam was being spread to cool. The increase in soil moisture per unit volume of soil is considerably less than the weight of steam used to heat the loam, the general increase being not more than 50 per cent. of the weight of steam. This difference is due in part to some steam being lost without giving up its heat, and in part to the escape of steam from the loam when it is left for the 10-minute period to complete sterilization by residual heat. The average increase in soil moisture content expected, if all the steam used is condensed, is 11 per cent. The observed average increase was 4·6 per cent.

Estimating boiler size.

The question of the size of boiler required to sterilize any given quantity of loam is often raised. Once the steam requirement per cubic foot of loam is known the capacity of a boiler in cubic yards of loam per hour can soon be calculated. From Table I we find that a medium clay loam, typical of that used for compost making and having a suitable moisture content, has a steam requirement of approximately 6 lb. per cubic foot when steamed under conditions of commercial practice. Table II gives, for a range of boiler sizes, the time taken to sterilize 1 cubic yard of loam at this steam requirement and also the maximum quantity of loam which could be sterilized in one hour. In giving this last figure, no allowance is made for the time which would be required to empty and refill the bin after each run. To obtain full output, a number of bins, used in rotation, would be required.

Design of steam grid.

Table I shows that there is an increase in the boiler rate of evaporation as the boiler pressure is increased. This indicates that there is a restriction in the line which limits the flow of low pressure steam ; the most obvious points are the $1\frac{1}{4}$-in. flexible hose joining the 3-in. steam main to the grid and the $1\frac{1}{4}$-in. steam valve. To determine which of these fittings was restricting the steam flow, boiler output

TABLE II.

Time taken to sterilize one cubic yard of loam by boilers of various sizes and their maximum capacity per hour.

Boiler size (steam lb./hr.)	Time to steam 1 cu. yd. (min.)	Maximum boiler capacity (cu. yd./hr.)
200	49	1·2
300	32	1·8
400	24	2·5
500	20	3·1
800	12	5·0
1,000	10	6·2
1,500	6	9·3

was measured with the 1¼-in. hose replaced by a 2-in. hose. Further, the pipe grid was disconnected and the amount of steam passed by the 1¼-in. steam valve, without the grid, was measured. There was no soil in the bins during these tests. The steam flow rates are given in Table III. These show that whilst both grids caused some restriction to the steam flow, the 1¼-in. steam valve was the main limiting factor. The size of the hose did not control the amount of steam passed by the grids. It would appear, therefore, that the only way in which full boiler output at low pressure could be obtained would be by re-designing the grid and using a larger capacity steam valve.

TABLE III.

The effect of pressure and hose size on the steam flow rates of two grids.

Boiler pressure (lb./sq. in.)	Steam evaporation rate per hour (lb.)					
	1¼-in. steam valve only		1¼-in. steam valve and grid			
			2¼-in. grid		4½-in. grid	
	2-in. hose	1¼-in. hose	2-in. hose	1¼-in. hose	2-in. hose	1¼-in. hose
15	800	790	747	730	695	726
25	1,156	1,140	1,060	1,035	1,012	1,024

It should be pointed out that two years elapsed between the experiments referred to in Tables I and III, therefore the possibility cannot be precluded that some internal corrosion of the grid or slight accumulation of soil had occurred. For this reason it is not legitimate to compare the two Tables.

DISCUSSION.

The experiments have shown that quantity of steam alone is the determining factor in the efficient sterilization of soil in bins. Consequently, it will be more economical for growers to use low pressure boilers and fit steam mains of adequate

size rather than to continue to purchase the more expensive high pressure equipment. Some pressure is required to overcome the frictional resistance of the pipe and especially the resistance of the steam valve and other fittings. 15 lb. per sq. in. at the boiler should be sufficient to work an efficiently designed bin system and this pressure can be obtained with the welded mild steel type boiler as used for glasshouse heating. When high boiler pressures are recommended for quick heating, the fact is overlooked that owing to a badly-designed pipe system an increase in pressure is very often accompanied by higher rates of steam production. It is this increase in quantity, not pressure, which is responsible for the more rapid heating.

In practice it often happens that the grid, by having a low total orifice area, restricts the flow of steam into the soil and so helps to maintain a high boiler pressure. From the data shown in Table III and Fig. 2 it is clear that, for low pressure steaming, a 1 cubic yard capacity grid of the type used should be fitted with a steam valve of at least $1\frac{1}{4}$-in. size and the total grid orifice area should be equivalent to that of the steam valve. As some steam loss from the ends and sides of the bin is inevitable no orifice should be closer than 4 inches from the edge.

Lawrence (1) has shown that rapid heating followed by immediate cooling, after the 10-minute period during which sterilization is completed by residual heat, is an important factor in avoiding the sterilizing check to plants which may follow when loam is kept at high temperatures for long periods. For this reason, and also because long heating periods require more steam, it is advisable to arrange the system so that all the loam can be heated within 15 minutes. If this cannot be achieved it indicates that the steam supply is insufficient, and the volume of loam being sterilized should be adjusted accordingly.

In the experiments, heating efficiency of the steam was very high, especially with short steaming periods. If the heat requirement (4) of the soil is taken as 33 B.T.U.s/cu. ft./° F. when the moisture content is 30 per cent., then the amount of heat required to raise the temperature to 212° F., is 158×33 B.T.U.s $= 5{,}214$ B.T.U.s, equivalent to 5·37 lb. of steam having 970 B.T.U.s of latent heat per lb. Comparing the general heating efficiency of steam with that of electricity under practical conditions, and taking 40 kw. per cubic yard for the electrode type sterilizer and 6 lb. of steam per cubic foot as average amounts of heat supplied, the electrical method uses 13 per cent. less heat than does the steam. This refers only to the heating of the soil and cannot be taken as presenting the overall thermal efficiency of the systems. Steam was injected into prepared loam at rates up to 0·78 lb. per cubic foot per minute, and there was no indication that this was the maximum rate at which it could be used under these conditions before the heating efficiency fell owing to the loss of uncondensed steam being greater than the saving effected by rapid heating.

SUMMARY.

1. Comparison was made of the efficiency of high (e.g. 40 lb. per sq. in.) and low (e.g. 5 lb. per sq. in.) boiler pressures under full-scale practical conditions for the sterilization of soil in bins.

2. Steam quantity was found to be of more importance than steam pressure, the time required to heat the soil being shortest when the quantity of steam was greatest, regardless of pressure.

3. The correct moisture content of a medium loam for sterilization was found to be 25-30 per cent. of the oven dry weight.

4. The quantity of steam required to raise the temperature of this loam from 54° F. to 212° F. was 6 lb. per cubic foot.

5. The increase in soil moisture content of loam, following sterilization, did not exceed 50 per cent. of the amount of steam used, mainly because of the escape of steam (moisture) from the loam whilst unloading from the bin.

6. A table is given which shows the effect of boiler evaporation rate on the time required to bring the loam to sterilization temperature.

7. In a properly designed system, a pressure of 2 lb. per sq. in. in the grid is adequate.

ACKNOWLEDGMENT.

The author wishes to express his thanks to Mr. W. J. C. Lawrence for his advice and interest in this work.

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THE RELATION BETWEEN THE RATE OF RESPIRATION OF AN APPLE FRUIT AND ITS CONTENT OF PROTEIN

II. THE VALUE OF THE RELATION IMMEDIATELY AFTER PICKING AND AT THE RESPIRATION-CLIMACTERIC FOR SEVERAL VARIETIES OF APPLES

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It has been suggested that the relation between the rate of respiration of an apple fruit (R) just before the onset of the climacteric and its content of protein (P) is characteristic of a variety and that culinary varieties tend to have lower values for the R/P ratio than dessert varieties (Hulme, 1951). Martin and Lewis (1952) have also shown that for apples grown in Australia respiration rate per unit protein is higher for light than for heavy crop fruit. These Australian workers do not find that culinary varieties necessarily have a low R/P ratio.

The present work was carried out to extend the earlier work to other English varieties and to examine the R/P ratio at the climacteric peak in respiratory activity. The climacteric peak is a precise point in the physiological development of the fruit (Kidd and West, 1930) and at this point the value of the CO_2-output appears to be characteristic of a variety in a given season. At all other points except one there is a steady drift in rate of respiration which makes it difficult to decide on a precise value for R in calculating the R/P ratio ; the exception is the short period immediately prior to the onset of the climacteric rise, and this period may easily escape sampling when a number of varieties are being picked over a number of seasons.

EXPERIMENTAL.

Preparation of material for analysis and methods of analysis. The methods used were those already described (see Hulme, 1950). The value of the CO_2-production at approximately 40 hours after detachment from the tree is taken as the initial rate of respiration on picking (Hulme, 1951).

Details of the fruit used. In all three seasons fruit was taken from mature trees grown at Ditton Laboratory, East Malling Research Station or a commercial orchard in Essex (Ardleigh). The source of the fruit is indicated in brackets after the name of the variety in the Tables. The variety Harvest is a new seedling raised by H. M. Tydeman at East Malling Research Station, but not yet distributed in commerce.

All the fruit was " normal " except for that from Miller's Seedling trees. This variety is a biennial bearer, but certain of the trees, all of which were in an off-year, had been induced to behave as in an on-bearing year by a treatment known as " bud-rubbing " (Davies, 1950) carried out in the previous season. Sets of apples

were taken from the induced " on " and the normal " off " bearing trees in the same orchard at the same time. The crop from the on-bearing trees was heavier and the fruit smaller than from the off-bearing trees.

The values of rates of respiration and of protein-content for all the varieties are the mean values for two carefully prepared samples, each comprising 25-30 fruits.

The samples used for the determination of the rates of respiration were prepared exactly as for the samples used for chemical analysis. They were placed in large " vacuum " desiccators which formed part of a train of apparatus used for the determination of CO_2-production (Hulme, 1937). The apparatus was operated in a room at 12° C. and two samples were removed for chemical analysis as near the climacteric peak as possible.

As a guide to the significance of the changes in the balance between protein and non-protein nitrogen over the period of the climacteric rise in respiration, the values of protein-N (P.N.) as a percentage of total-N (T.N.) for all the samples have been grouped together and the standard deviation (S.D.) calculated by the usual methods.

The date of petal-fall is not known for all the varieties, but as an indication of the type of season, the date of petal-fall for Cox's Orange Pippin apples was in 1950, 17th May ; in 1951, 28th May ; and, in 1952, 10th May.

Results.

Details of variety, date of picking, days at 12° C., rate of respiration and nitrogen content are shown in Table I.

Under " remarks " in Table I an indication is given if the climacteric rise in respiration had already set in on the tree when the fruit was picked. Thus " $C\frac{1}{4}$ " indicates that about one quarter of the climacteric rise had already taken place when the " initial " measurement of R was made.

Table II shows the extent of the rise in rate of CO_2-production per 100 g. of tissue which occurs between the onset of the climacteric and its peak value (column 5), together with the rate of increase per day (column 6). These values were obtained from the records of CO_2-production ; they do not necessarily agree exactly with the results shown in Table I since the times of the onset of the respiration climacteric and of its peak did not always correspond with the times at which the samples were taken for chemical analysis. Since, however, in mature apples the net amount of protein present does not change to any great extent in the few days before the onset of the climacteric, or for several days after the climacteric peak, the observed rise between the two sampling times in the percentage of nitrogen in the form of protein (P.N. as a percentage of T.N., see Table II) may legitimately be compared with the rise in CO_2-production over the period of the respiration climacteric. Total nitrogen does not change during storage (Hulme, 1936).

R/P values at the climacteric peak for Bramley's Seedling apples in 1936, 1938 and 1939 (Hulme, 1950) are included in Table II for purposes of comparison. The R/P ratios of the other varieties are calculated from the results given in Table I.

DISCUSSION.

The standard deviation, based on 29 degrees of freedom, of the difference between the means of duplicate samples of protein nitrogen as percentage of total nitrogen for all the samples (all varieties) for 1950, 1951 and 1952 was 1·7. Since the observed

TABLE I.

The protein nitrogen content and respiration rate of several varieties of apples.

Variety and year	Date of picking	Days in store at 12° C.	Fresh weight per apple (g.)	R. (mg. CO_2 per apple per 100 hrs.)	T.N. per apple (mg.)	P.N. (P) per apple (mg.)	P.N. as % of T.N.	Remarks
Miller's Seedling, 1950 (on-bearing)	15th Aug.	0	71·0	74·8	49·2	22·6	45·9	
		15	71·0	148·2	47·2	23·5	49·8	
Miller's Seedling, 1950 (off-bearing)	15th Aug.	0	80·8	173·0	51·5	24·1	46·8	$C\frac{1}{4}$
		14	80·2	253·5	48·7	28·4	58·3	
Worcester Pearmain, 1950 (Ditton)	29th Aug.	0	81·4	154·5	50·2	31·9	63·5	$C\frac{1}{8}$
		9	81·0	204·3	48·8	34·5	70·7	
Cox's Orange Pippin, 1950 (Ardleigh)	18th Sept.	0	133·2	189·1	84·4	45·0	53·3	
		19	137·5	342·1	82·0	48·2	59·0	
Cox's Orange Pippin, 1950 (Ardleigh)	22nd Sept.	0	154·4	260·0	92·3	51·5	55·8	
		19	153·8	395·2	91·6	56·1	61·5	
Gladstone, 1951 (East Malling)	9th Aug.	0	64·4	180·3	36·6	26·7	72·9	$C\frac{1}{5}$
		9	63·9	266·2	35·8	29·1	81·3	
Harvest, 1951 (East Malling)	10th Aug.	0	57·6	97·0	51·4	28·0	54·4	
		15	58·2	172·3	46·1	27·4	59·5	
Tydeman's Early Worcester, 1951 (East Malling)	20th Aug.	0	82·6	150·0	55·1	34·7	63·1	
		12	82·1	257·0	54·4	40·1	73·7	
James Grieve, 1951 (East Malling)	7th Sept.	0	93·0	137·9	60·1	31·9	53·1	$C\frac{1}{10}$
		13	92·7	213·2	57·4	33·3	58·1	
Cox's Orange Pippin, 1951 (East Malling)	24th Sept.	0	103·4	148·9	60·4	32·3	53·4	
		13	103·1	230·9	61·8	36·9	59·7	
Cox's Orange Pippin, 1951 (Ardleigh)	24th Sept.	14	109·8	237·2	65·8	37·3	56·7	
Cox's Orange Pippin, 1952 (Ardleigh)	9th Sept.	0	102·8	174·6	70·9	38·5	54·2	6 days pre-C.
		24	102·3	268·8	72·8	42·5	58·4	
Cox's Orange Pippin, 1952 (Ardleigh)	17th Sept.	0	106·9	172·3	70·1	36·9	52·6	5 days pre-C.
		21	106·5	268·2	71·0	41·8	58·9	
Cox's Orange Pippin, 1952 (Ardleigh)	26th Sept.	0	110·5	195·6	72·1	39·8	55·3	$C\frac{1}{10}$
		17	109·8	292·1	70·8	44·0	62·2	
Cox's Orange Pippin, 1952 (Ardleigh)	8th Oct.	0	117·5	284·3	72·2	41·5	57·5	$C\frac{3}{4}$
		15	116·2	334·4	75·2	45·8	60·9	6 days post-C.

TABLE II.

Rates of respiration, protein-nitrogen content and R/P ratios of several varieties of apples.

Variety	Date of picking	Respiration rate (mg. CO_2/100 g./100 hrs.)				Rise in P over climacteric P.N. as % T.N.	R/P ratio*	
		Minimum	Climacteric maximum	Increase	Increase per day		"Initial"	At climacteric peak
Miller's Seedling (on-bearing)	15th Aug., 1950	94	208	114	10	3·9	3·3	6·3
Miller's Seedling (off-bearing)	15th Aug., 1950	174	318	144	13	11·5	7·2	8·9
Worcester Pearmain (Ditton)	29th Aug., 1950	180	268	88	11	7·2	4·8	6·0
Cox's Orange Pippin (Ardleigh)	18th Sept., 1950	136	250	114	8	5·7	4·2	7·0
Cox's Orange Pippin (Ardleigh)	22nd Sept., 1950	160	259	99	7	5·7	5·0	7·0
Gladstone	9th Aug., 1951	268	415	147	15	8·4	6·8	9·2
Harvest	10th Aug., 1951	150	295	145	14	5·1	3·5	6·3
Tydeman's Early Worcester	20th Aug., 1951	180	315	135	13	10·6	4·4	6·4
James Grieve	7th Sept., 1951	138	230	92	7	5·0	4·3	6·4
Cox's Orange Pippin (East Malling)	24th Sept., 1951	143	229	86	6	6·3	4·6	6·3
Cox's Orange Pippin (Ardleigh)	24th Sept., 1951	124	215	91	7	—	—	6·4
Cox's Orange Pippin (Ardleigh)	9th Sept., 1952	142	264	122	8	4·2	4·5	6·3
Cox's Orange Pippin (Ardleigh)	17th Sept., 1952	140	256	116	8	6·3	4·7	6·4
Cox's Orange Pippin (Ardleigh)	26th Sept., 1952	164	265	101	7	6·9	4·9	6·6
Cox's Orange Pippin (Ardleigh)	8th Oct., 1952	(In final stage of climacteric on tree)				3·4	6·8	7·3
Bramley's Seedling	21st Sept., 1936							4·6
	5th Oct., 1936							4·8
	15th Sept., 1938							4·7
	5th Oct., 1938							5·2
	13th Sept., 1939							4·6
	4th Oct., 1939							5·0

* Calculated from data in Table I.

increases (Table II, column 7) range from 3·4 to 11·5, it is clear that there is a significant rise in net protein content over the period of the climacteric rise in respiration in all the varieties. This rise was first noticed in Bramley's Seedling apples in 1936 (Hulme, 1936) and has been discussed at length elsewhere (Hulme, 1954).

The early varieties have a high rate of increase in CO_2-output during the period of the climacteric rise coupled with a large increase in net-protein content. The rise in R is, however, relatively greater than the increase in protein, with the result that these early varieties tend to have a high R/P ratio. The Harvest and Miller's Seedling (on-bearing) are apparent exceptions to this rule ; the rate of increase in CO_2-production is high, but the overall respiration-rate and increase in protein is low, the R/P ratio practically doubling over the climacteric. The Harvest variety (Worcester Pearmain × Devonshire Quarrenden) requires further study. The treatment given to induce an on-bearing fruit in an off-bearing season may have introduced some abnormal element into the on-bearing Miller's Seedling apples.

Apart from Miller's Seedling (on-bearing) and Harvest, there is at the climacteric peak, a sequence in the R/P values : Early varieties—Gladstone, Miller's Seedling, Early Victoria (Hulme, 1951)—7·7 to 9·2 ; mid-season and late varieties—Tydeman's Early Worcester, Worcester Pearmain, James Grieve and Cox's Orange Pippin—5·9 to 7·0. All these varieties, except Early Victoria, are dessert apples. Bramley's Seedling, a culinary variety only slightly later than Cox's Orange Pippin, exhibits R/P values between 4·5 to 5·2. The present results, therefore, again suggest that with English apples, dessert varieties tend to have higher R/P values than culinary varieties, the earlier maturing kinds having the highest values. This result cannot, however, be considered as established until more late culinary varieties have been examined.

If the difference between the two examples of Miller's Seedling apples is treated as a simple one between light and heavy crops in the same season then, in conformity with the results of Martin and Lewis (1952), the effect of a light-crop fruit is to increase the higher R/P value. It also appears that on-bearing fruit develops rather later than off-bearing fruit since, in the present instance, the climacteric rise had already just commenced on the tree when the off-bearing fruit was picked, while the on-bearing fruit picked at the same date was still in the pre-climacteric state by one or two days. (Table I.) Martin and Lewis found that such fruit did not keep well. In the variety Cox's Orange Pippin, for which results over several seasons and from two different localities are available, the variation in the R/P ratio is surprisingly small, at least up to the time when the respiration climacteric has already commenced on the tree. It is possible that even these small changes in R/P values may be linked with keeping quality. In view of the apparent fundamental character of the R/P value and of the importance to the industry of a forecast of keeping quality, an extended survey of R/P values in relation to keeping quality for a selected range of apple varieties might prove invaluable.

SUMMARY.

1. Data on the rate of CO_2-production during the climacteric rise in respiration and the rise in net protein content over the same period for a number of early, mid-season and late varieties of English apples are presented.

2. The ratio of rate of respiration to protein-content (R/P ratio) at the climacteric peak is found to be high in dessert varieties, especially those maturing early in the season.

3. Within a variety, during several seasons and from different localities, the R/P value at the climacteric peak is shown to be surprisingly constant, provided the respiration climacteric has not proceeded far on the tree before the fruit is picked.

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STUDIES IN THE DEVELOPMENT OF THE STRAWBERRY

I. FLOWER-BUD INITIATION AND DEVELOPMENT IN EARLY- AND LATE-FORMED RUNNERS IN 1951 AND 1952

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THIS paper reports part of an investigation of normal bud development in the strawberry plant, a necessary preliminary to studies on influences of environment and changes induced by diseases. Darrow (1929), Waldo (1930) and others have described the development of inflorescences and runners in North American strawberries, whilst Guttridge (1952) has reported dates of inflorescence initiation in three British varieties grown under outdoor conditions at Long Ashton Research Station and discussed their growth habits. The present results were obtained with plants grown in open ground at Mylnefield. More detailed observations on the initiation and development of stolons and runner-plants will be given later.

MATERIALS AND METHODS.

Single first-year plants of the varieties Sir Joseph Paxton and Royal Sovereign (M.48), and second-year plants of Auchincruive Climax and Royal Sovereign (a selection of M.40, termed 1/1), were planted out from pots in May, 1951. Runners were pegged down at weekly intervals and each labelled with the approximate date of expansion of the first fully developed leaf. Collections of runners were made fortnightly from 21st September. The crowns were fixed in Bouin's fluid, sectioned in wax, and stained with Safranine, with or without Light Green. Similar material raised in 1952 was examined by dissection, fresh or after fixation in formalin-aceto-alcohol.

The degree of differentiation of the anthers of the terminal flower was taken as a measure of inflorescence development, based on the following arbitrary stages :

0 — anther initials not recognizable ;
1 — initials circular in cross section ;
2 — initials rectangular in cross section, with no internal differentiation seen under low-power magnification ;
3 — anthers slightly lobed, with dark-staining archesporia ;
4 — anthers lobed, with tapeta and spore-mother-cells ;
5 — meiosis occurring ;
6 — tetrads present ;
7 — pollen present.

In April, 1952, some remaining material was used in a small experiment to compare the field behaviour of runners of varying ages. Royal Sovereign and

Paxton runners of five ages, and Climax runners of three, were planted normally and later given the following treatments :

(*a*) de-blossomed but allowed to bear stolons ;

(*b*) de-stoloned but allowed to flower and fruit ;

(*c*) allowed both to fruit and bear stolons.

Royal Sovereign and Climax were used in units of three plants for each age/treatment combination and Paxton in units of two, save for some earliest-formed runners which were used singly. The production of flowers, primary stolons (stolons emerging directly from the mother plant) and secondary (branch) crowns was recorded.

Some confusion exists in the terminology denoting age in strawberry plants. Here the terms " runner " or " runner-plant " are applied from the formation of the plant until the recommencement of growth in the following spring, when, under most cultural systems, final transplanting is completed. The plants are then termed " first-year " until the following winter, and afterwards " second-year ", and so on.

RESULTS.

Typical development of a young crown.

The writers' observations on the growth and development of the stem axis agree closely with those of Guttridge (1952), whose terminology will largely be adopted. A young runner-plant consists of a short primary axis bearing leaves and leaf initials in spiral succession and terminated by a vegetative growing point. In summer or autumn the latter develops into a " first order " inflorescence, extension growth of the crown being continued by the youngest, or uppermost, axillary bud. The secondary crown-extension axis so formed may later terminate in a " second order " inflorescence, any further extension growth again arising from the axillary bud immediately below. This forms a tertiary crown-extension axis, which in turn may end in a third order inflorescence ; and sometimes further growth may produce a fourth order inflorescence. Thus each inflorescence is terminal, and the growth habit sympodial. The youngest axillary bud, which extends the growth of the crown, may, for convenience, be termed the " adjacent " bud (Fig. 1), though noting that it is only one of several buds normally present on each section of the axis.

The behaviour of other axillary buds varies, both with variety and with the time of formation of the runner. Until late autumn the oldest (lowest) bud of a new runner usually forms a " continuation " stolon, extending the runner series. Younger buds, especially in early-formed plants, may also produce stolons or may develop in autumn or winter into secondary crowns—branches of the main axis—with or without terminal inflorescences. Some buds remain small and vegetative during winter : of these the oldest may form secondary crowns in spring when the youngest, on the most recent extension axis, often produce stolons. Still other buds enter winter each with a few leaf initials and a small apical inflorescence of few flowers. Such " axillary " inflorescences (as distinct from larger ones terminating secondary crowns) were found in all three varieties studied, mainly in early-formed runners. They are initiated in late autumn and develop slowly. Any that emerge flower some weeks after the main inflorescences of primary and secondary crowns ; but the majority cease development and die.

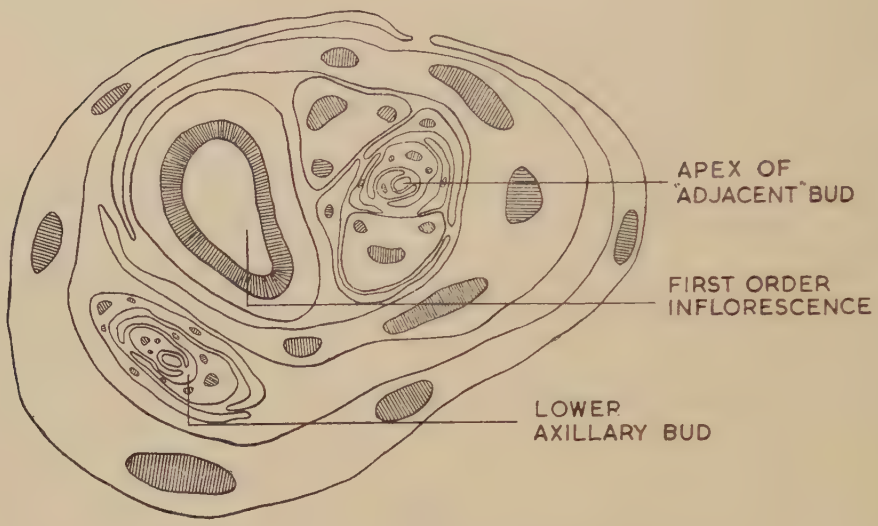

FIG. 1.
Cross-section of crown of a runner-plant in autumn.

Structure of the inflorescence.

The strawberry inflorescence is of cymose type but shows much diversity of form. In the varieties studied, three component units may be distinguished: (i) the terminal flower; (ii) " simple " branches, with from one to three flowers; and (iii) " complex " branches, with more than three but rarely above seven flowers (Fig. 2, i). One or more branches of each type may be present, and the varied flower numbers of the branches can give inflorescences of widely differing size with the same basic structure (Fig. 2, ii). For each branch-combination, however, there are minimum and maximum numbers of flowers that could, in theory, be present: these are plotted in Fig. 3 for twelve combinations examined. (Only in a few large inflorescences were complex branches found with over seven flowers.) The diagram also shows which flower numbers were actually observed. Thus an inflorescence of twelve flowers could be formed in seven ways, of which three were observed. Further variation arises from the arrangement of a given number of flowers on a given branch structure (Fig. 2, iii).

In practice, an inflorescence of seven flowers seems to contain two simple branches or one simple and one complex branch, and most eleven-flower inflorescences (a frequent form) have one branch of each type. As will be seen, some features of inflorescence structure appear characteristic of varieties.

*Inflorescence initiation and development in runners of known age.**

1. *Sir Joseph Paxton.* Runners of Paxton formed from mid-July to mid-September, 1951, were vegetative on 21st September and 6th October. On 20th

* Numerical records on which statements in this section are based are available on application to the Institute.

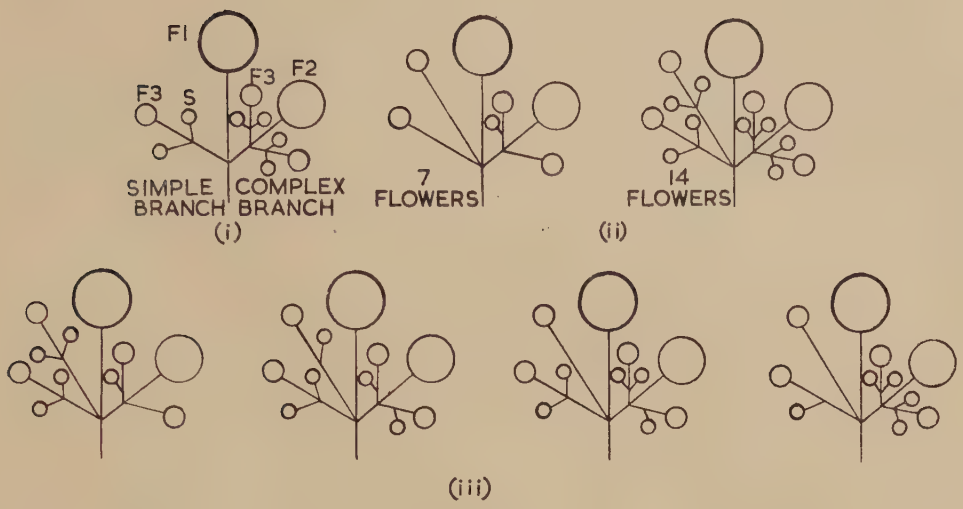

FIG. 2.

Diagrams of inflorescence structure.

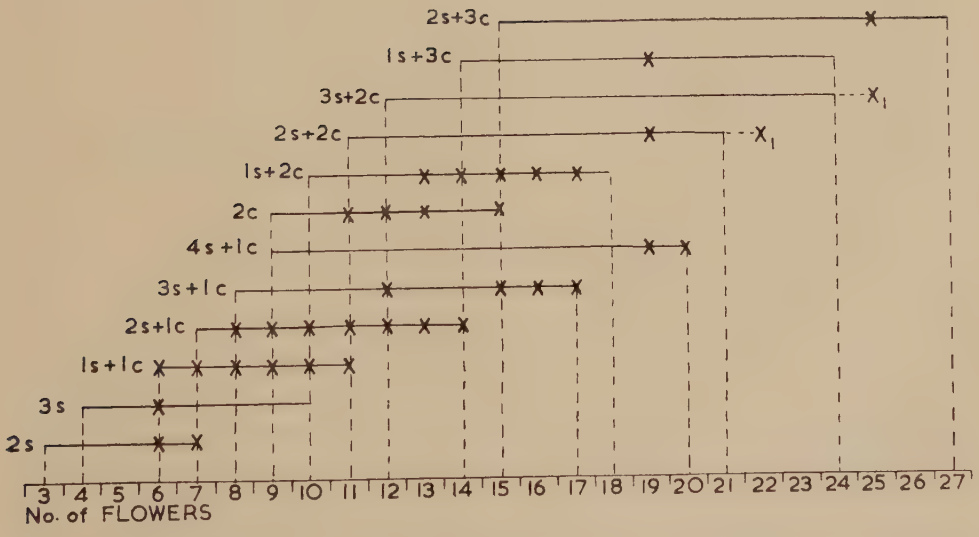

FIG. 3.

Range of possible flower numbers in 12 different inflorescence structures, and the numbers observed (X). (X_1 denotes exceptional numbers, where complex branches had 8 flowers. s = simple branch; c = complex branch.)

October a plant dated 8th September contained a first order inflorescence of 5 flowers, and on 2nd November inflorescences were present in three plants formed from 11th August to 6th October. It was concluded that flower initiation had begun at about the end of the second week of October. This was confirmed in runners of corresponding age in 1952, when, however, earlier runners dated prior to mid-July contained inflorescences by the end of September. Late September, therefore, may mark the onset of flower initiation in early runners of this variety. Several September- and October-formed runners remained vegetative in autumn, 1951, and later examinations and field records gave no evidence that such plants developed inflorescences in the spring.

In autumn, 1952, first-year plants developed inflorescences 2-3 weeks before runners. The original formation dates of these plants still influenced their individual times of flower initiation, though less markedly than in the previous year.

Flower initials in first order inflorescences of the 1951 runners averaged about 6 until late January or February. They later increased, especially in the older plants, reaching an average of about 14 by March and April. It appears that although inflorescences may not be initiated in spring, those already formed develop more flowers. Field records of flowering showed that many of the late-formed initials reached maturity, and that the earliest-formed runners bore most flowers.

Flowers of Paxton at first develop slowly. By 11th January, 1952, no terminal flower examined had reached stage 2, but in February and March there was differentiation of the archesporium and tapetum, stage 4 being reached by mid-March. In most inflorescences terminal flowers of branches were then as advanced as the main terminals, and plants of different age-groups varied little in development. Further differentiation was rapid, pollen forming by mid-April.

Most plants in the field had inflorescences at " green-bud " stage (when the first flowers are visible, but the sepals not unfolded) on 28th April. Main terminal flowers opened from 19th to 26th May, terminals of complex branches generally three days later, and F_3 flowers (Fig. 2, i) from the 23rd to 26th, the majority on the 26th. Secondaries (Fig. 2, i) flowered from 31st May to 20th June.

The Paxton inflorescence has typically three branches, the third usually occurring where the flowers exceed seven. Alternative lines of development then converge in a 12-flower form of one complex and two simple branches. In larger inflorescences either a fourth branch arises or a simple branch becomes complex.

Second order inflorescences were not found. The " adjacent " bud generally remained small until late March, with 1-2 leaf initials and a vegetative apex, and then recommenced growth to extend the crown. The lower axillary buds of the primary axis were generally larger and more highly differentiated than those of Royal Sovereign or Climax. A few, mainly in early runners, formed axillary inflorescences, late and slow in development and with few flowers. None of these emerged in spring. Other buds, mainly the lowest on the stem axis, formed secondary crowns in autumn, some with terminal inflorescences. The latter were initiated late, bore few flowers, but blossomed in spring about three days after the inflorescences of main crowns.

2. *Royal Sovereign M.48.* Runners of M.48 formed from 7th July to 15th September, 1951, were vegetative on 21st September, but on 6th October two plants, dated 28th July and 18th August, contained first order inflorescences. Flower initiation had apparently started near the end of September. In 1952, flower

primordia were seen in one of two runners examined on 19th September and each of three examined on 30th September, the plants being dated from 4th to 7th July. This earlier record may have been due to the season, but more probably, as in Paxton, to earlier runners having been examined. From the combined records it appears that flower initiation begins earlier in Royal Sovereign than in Paxton, perhaps by 1-2 weeks. Occasional runners—fewer than in Paxton—remained vegetative.

First-year plants in 1952 initiated flowers in the first fortnight of September, at the same time as, or possibly just before, the earliest runners.

By November, 1951, first order inflorescences of most early runners carried over 12 flowers, but the increase of primordia in spring was less than in Paxton. The Royal Sovereign flowers also underwent earlier differentiation, reaching stages 2 and 3 by mid-January. Field plants reached " green-bud " about a week before Paxton, and first terminal flowers opened 3-4 days earlier. As in Paxton, most late-formed flowers on main inflorescences reached maturity, and the earliest runners produced most flowers.

Royal Sovereign inflorescences of 9 flowers contained a simple and a complex branch, after which either the simple branch became complex, giving a maximum of 15 flowers, or a second simple branch occurred, giving a maximum of 14. Higher flower numbers occupied four or five branches, two or three of them complex. The second simple branch was not seen in inflorescences of under 10 flowers, whereas in Paxton it usually entered with the 8th flower.

Several runners formed up to 6th October (about a third of the total examined in winter and spring) developed second order inflorescences, initiated late in autumn after the formation of 2-4 leaf initials on the secondary crown-extension axis. These bore fewer flowers than first order inflorescences and flowered some 10 days later.

Most runner crowns carried 7-9 axillary buds, with 12 or more in earliest-formed plants. Axillary inflorescences were not seen in the 1951 runners until mid-November, but by February as many as 6 were present in some early plants. An early 1952 runner (dated 4th July) had flower primordia in 4 axillary buds by late October. Inflorescences that remained " axillary " nearly always carried few flowers and were late in development, reaching stages 1-2 in February and progressing little further. Buds that produced secondary crowns formed larger inflorescences, which reached stages 3-4 by early April and flowered.

3. *Royal Sovereign 1/1.* Any differences in times of flower initiation between comparable plants of this clone and M.48 were slight, 1/1 possibly being the earlier. Inflorescences of M.48 generally carried more flower primordia during development and more flowers in the field, but inflorescence structure and dates of emergence and flowering in the two clones were closely similar. More vegetative plants occurred in 1/1, and second order inflorescences were fewer. Axillary buds were as numerous as in M.48, but fewer formed inflorescences. As in Paxton and M.48, the only such inflorescences that flowered were from buds that had formed secondary crowns.

4. *Auchincruive Climax.* Flower-bud development in early Climax runners was too advanced at the first examination in 1951 for initiation dates to be estimated. In 1952, runners dated 14th June and 19th July contained inflorescences on 18th August, and most plants formed up to 6th September had inflorescences on 30th September. Initiation probably began in early plants in the first week of August, possibly even earlier in first-formed runners. In both years several runners formed after early September remained vegetative.

The earliest inflorescences differed in development rate from those initiated later. In 1951, flowers in plants dated 28th July contained pollen by mid-November, when the oldest flowers of September-October plants were at stages 1-3. Many inflorescences of early plants reached "green-bud" in November, those of later plants not until spring. Some early 1952 runners actually flowered in October, but most plants that year behaved similarly to Royal Sovereign.

Climax inflorescences usually consist of one complex and one or two simple branches, with up to 14 flowers. Further branches enter with higher flower numbers. First order inflorescences typically have short peduncles, branching at a single point, but later ones usually have longer peduncles. In both years early runners produced more inflorescences in the field, each type with more flowers, than later runners.

The terminals of some first order inflorescences opened on 16th May, 1952, with the first flowers of Royal Sovereign, but Climax shows more tendency for plants to flower in the order of their formation as runners. Terminals of complex branches floweréd about three days after the main terminals, and small secondaries opened until mid-June.

Few runners were available in 1951, but about a third of those examined in autumn—mainly early plants—had second order inflorescences. These were generally smaller than first order inflorescences and flowered about a week later. Two third order inflorescences were seen in the field.

The 1951 runner crowns bore 7-12 axillary buds by mid-winter, according to age. Most of these produced axillary inflorescences, initiated usually a few weeks after, but sometimes before, the first order inflorescence. These inflorescences developed slowly, but one was seen at stage 3 in early March and two small ones flowered. In this respect Climax differed from Paxton and Royal Sovereign. In many plants the second youngest axillary bud of the primary axis became highly differentiated and formed a secondary crown in the following spring. The "adjacent" bud remained small in winter, with 2-4 leaf initials, and resumed vegetative growth in spring.

Spring flowering in first-year plants in 1952 ceased by mid-June, and by late June some of the older plants had initiated new inflorescences. Younger ones (those formed later the previous year) initiated flowers in July or grew vegetatively until early autumn. Where the summer initiation occurred, development was rapid, first order inflorescences emerging from 25th July to 12th August and flowering. Several second order inflorescences were formed, and in one plant third and fourth inflorescences had emerged by late September. Plants lacking the summer initiation were vegetative until mid-September, when nearly all first-year plants formed terminal inflorescences for the following year. Simultaneously, flowers were formed in most axillary buds. Thus, although Climax resembles Paxton, and possibly Royal Sovereign, in forming flowers earlier in first-year plants than in runners, many of the former "lose" their early inflorescences by immediate flowering, and inflorescences to produce the following year's crop are initiated later. Here, in 1952, they were initiated after those of the earliest runners, few of which flowered in autumn.

DISCUSSION.

Although this work was confined to young plants and to two particular years, the results show clearly that strawberry varieties, grown under similar conditions,

differ in times of inflorescence initiation and number and distribution of flower primordia. A feature common to the varieties studied is their formation of many small inflorescences in axillary buds, few of which reach maturity. Dates of flower initiation recorded in Royal Sovereign and Auchincruive Climax agree closely with those reported by Guttridge (1952) from south-west England, the differences probably being within the range of normal plant variation.

The results are related to horticultural experience. Sir Joseph Paxton, when grown in Scotland, showed moderate cropping capacity, whereas Climax crops heavily in summer and occasionally yields from its late summer flowers. Most growers of Climax consider its late summer flowering to be non-detrimental to the following year's crop, and although this may not strictly be so, it is clear that inflorescences are initiated in ample quantity after the first have emerged. Its sequence of flower formation suggests that this variety may be less subject than some others to the influence of day length (Darrow and Waldo, 1934).

SUMMARY.

1. Early-rooted runners of Auchincruive Climax, Royal Sovereign and Sir Joseph Paxton strawberries, grown near Dundee, began to form flower primordia approximately in early August, early to mid-September and late September respectively. In one year a few early Climax runners flowered in autumn.

2. First-year plants of Royal Sovereign formed primordia at the same time as, or slightly before, new runners. Those of Paxton did so 2-3 weeks sooner than their runners. Those of Climax either formed flower primordia in late June and July, the resultant inflorescences flowering shortly afterwards, or grew vegetatively until mid-September, when most first-year plants of this variety began to form inflorescences for the following year.

3. Dates of flowering, and numbers of flowers borne, varied with the positions of origin of inflorescences on the crown. Inflorescences in small axillary buds seldom reached maturity.

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THE INSECTICIDAL EFFICIENCY OF DDT DEPOSITS APPLIED TO APPLE FOLIAGE AS SOLUTIONS OR EMULSIONS*

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SYNOPSIS.

The toxicity of deposits of DDT on leaves as a contact insecticide is affected by factors tending to reduce the deposits. Among these is penetration of DDT into the leaf-tissue where it is lost for this purpose. A study was made of the influence of formulation upon penetration as judged both by chemical recovery of DDT from the surface of treated apple leaves and by the toxicity of deposits on such leaves to the stored-products pest, *Tribolium confusum* Duv. Penetration was shown to increase from suspension through emulsion to solution and also, relatively, as the concentration of DDT in a given formulation was reduced. The rate of loss of these superficial deposits by weathering was found to fall off regularly with time of exposure. The DDT inside the leaf was not available as an insecticide for the insect used in these tests.

As early as 1945, Gunther (1945) reported that in California, where shade temperatures may reach 125° F., DDT deposits on foliage may lose their insecticidal value within two weeks. The reason for this was not clear but, soon afterwards, Stiff and Castillo (1946) demonstrated the absorption of DDT into a number of building materials and fabrics and showed that greater penetration occurred when the DDT was applied in solution than when in the form of an emulsion. These workers forecast that similar results would be obtained if DDT were applied in these forms to foliage or fruit. Ebeling (1945) had already shown that DDT painted on leaves and twigs of *Citrus* spp. as a 4 per cent. kerosene solution would penetrate the plant tissue but that this penetration was largely prevented by the addition of 1-2 per cent. aluminium stearate to the solution. Gunther, Lindgren, Elliott and LaDue (1946), also spraying citrus trees, found that the amount of DDT deposited varied with the nature of the solvent used and that the insecticide both penetrated the tissue and, at least in part, came up again to the surface subsequently. Symes (1946), working on tropical vegetation, found that the proportion of DDT absorbed varied with the character of the leaf; some of the insecticide could be recovered by simple washing but the rest only after prolonged Soxhlet extraction. That this " loss " of DDT by penetration could lead to erroneous conclusions about surface deposits was emphasized by Wichmann *et al.* (1946), who found that prolonged shaking of DDT-sprayed apples with benzene led to less and less DDT being removed, due (they considered) to the benzene penetrating the fruit and carrying DDT in with it.

Apart from Ebeling (1945) who painted on DDT in kerosene, and Stiff and Castillo (1946) who applied solutions or emulsions from a micropipette to the surfaces they used, the workers quoted above applied DDT with ordinary spraying equipment.

* Based on a thesis presented to the University of London for the degree of Doctor of Philosophy.

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Thus there was no certainty regarding the amount of DDT deposited on any given area, and hence no idea of the extent of penetration could be obtained. The value of any preparation of DDT as a contact insecticide on fruit trees will obviously depend on the amount of DDT deposited from that preparation, modified by the extent to which it penetrates the plant tissue and becomes, presumably, unavailable. The work of Stiff and Castillo (1946) showed that formulation could be expected to affect the extent of penetration. A study of such influences on apple foliage was undertaken in 1946.

Two approaches to the problem were possible: (*a*) the chemical estimation of the superficial residues, and (*b*) biological assay of these residues with a convenient test-insect. Both methods could also be used to examine the effect of field conditions upon the persistence of the deposit. It was realized that DDT *within* leaf-tissue might be effective as a stomach-poison against chewing insects, but the present work was confined to a study of the toxicity of DDT in various formulations as a contact insecticide on leaves. A standard procedure for the chemical estimation of DDT residues was adopted throughout and a technique of biological estimation was also developed. These two methods of evaluation were employed for deposits applied under standard conditions, both without and following weathering (Satyanarayana, 1948).

In commercial practice, technical DDT is used but Haller *et al.* (1945) have shown that such material contains at least thirteen by-products of which the *o,p'*-isomer may be present to the extent of some 20 per cent. The task of analysing such mixtures is formidable and it was decided to simplify the work by using pure *p,p'*-DDT.

MATERIALS AND METHODS.

(*a*) *Solvents and emulsifiers.* Seven solvents, *n*-hexane, benzene, petroleum ether (80-100° C.), pyridine, diacetone alcohol, dekalin and cottonseed oil, were used in the preparation of solutions or emulsions of DDT. The four emulsifiers used were sodium oleate (anionic), MB320 (*cyclo*hexylamine salt of sulphonated lorol, anionic), Fixanol (cetyl pyridinium bromide, cationic), and Triton X-100 (alkyl aryl polyether alcohol, non-ionic).

(*b*) *DDT and formulations.* Pure *p,p'*-DDT, m.p. 107-108° C., was prepared from a commercial sample of DDT by recrystallizing thrice from 98 per cent. ethanol.

Solutions of DDT and sodium oleate emulsions were readily prepared. With the other emulsifiers, however, hand-shaking failed to establish good emulsions; success was achieved by passing the coarse emulsions four times through a colloid mill. The DDT content was established in each case by analysis.

(*c*) *Deposition of insecticide.* Leaves of apple, variety Cox's Orange Pippin, were used exclusively in this work. In the first few experiments 10 leaves weighing 5·0 g. were used per test, but this procedure was abandoned in favour of using a standard area of 200 sq. cm. Several leaves were trimmed to a standard ovoid shape, after having been wiped clean and dry and flattened by weighting. These leaf-areas were then spread out in petri-dishes for the application of the insecticide.

When using a Tattersfield tower, dekalin and cottonseed oil emulsions deposited larger quantities of DDT than did a benzene emulsion. This method of deposition was therefore discarded and the following procedure adopted. 1 ml. of solution or

emulsion, containing 10 mg. DDT, was measured accurately with a micropipette and deposited on the entire leaf area as uniformly as possible ; a bent needle was finally passed over the area to make even the deposit. Deposition on the lower surface of leaves was more difficult than on the upper surface on account of the midrib and veins, but the degree of obstruction was not great. All tests were carried out in duplicate or, where necessary, quadruplicate.

Treated leaves were left in petri-dishes for a period of 24 hours in an unheated room with a northerly aspect before analysis was begun.

(*d*) *Extraction of the deposit.* The leaves were transferred to 500-ml. conical flasks, taking care not to disturb the deposits and transferring any DDT which had fallen into the dishes by swabbing with benzene-moistened cotton-wool, which was added to the flasks. 50 ml. benzene was added and the flask stoppered and shaken by hand for 5 minutes. The benzene was run off into a 100 ml. volumetric flask and the procedure repeated with 30 ml. and again with 25 ml. benzene. The volume was finally made up to 100 ml. ; 50 ml. aliquots, each containing half the easily-accessible deposit, were taken for analysis.

(*e*) *Method of analysis.* As only pure *p,p'*-DDT was likely to be present in the deposit, the total chlorine was converted to chloride by the method of Stepanov (1906), using sodium and ethanol; the use of *iso*propanol, suggested by later workers, was not found satisfactory.

Benzene was removed under reduced pressure by gently warming on a water-bath. 2 g. sodium and 25 ml. ethanol were added and, after the reaction had subsided (10 minutes), the flask was heated under reflux at 80° C. for half an hour. The contents were then neutralized with nitric acid, and the chloride estimated by the Volhard procedure, adding 5 ml. nitrobenzene and 3 ml. 11·7 per cent. ferric nitrate solution, and titrating with 0·02 N silver nitrate and ammonium thiocyanate.

(*f*) *Biological tests.* Tests were made of the insecticidal activity of deposits, using adults of *Tribolium confusum* Duv., which does not fly or climb glass and can therefore readily be confined on a treated surface. Squares of fresh leaf were cut, 8 sq. cm. in area, and laid in petri-dishes ; measured quantities of insecticide were then deposited as usual. When the deposits had dried (1 to 2 hours), circles were cut from the squares and fitted into the caps of " Universal " screw-cap bottles which have rubber washers. Fifteen insects, kept without food at 25° C. for the previous 24 hours, were placed in each bottle ; the cap screwed on and the bottle finally inverted so that the insects were brought in permanent contact with the leaf-surface. The bottles were stored at 25° C. and mortality counts carried out after 6 days.

RESULTS.

1. *The effect of the nature of the solvent used for preparing the solution on the amount of DDT recovered.*

The percentage recoveries of DDT from leaves treated with 1 per cent. solutions of this insecticide are shown in Table I.

Severe scorching of both surfaces of the leaves was caused by all solutions except that in cottonseed oil. Crystalline deposits were left by all of the first six solvents, but the cottonseed oil neither evaporated nor entirely entered the leaves. Only 80 to 85 per cent. of the DDT applied in cottonseed oil could be recovered ; after applications in the other solvents, less than 80 per cent. was recovered from

TABLE I.

Percentage recovery of DDT applied in various solutions.

Solvent	Specific gravity	Boiling point, ° C.	Mean percentage DDT recovered	
			Upper surface	Lower surface
1. *n*-Hexane	0·660	69	78·0	69·5
2. Benzene	0·879	80	74·8	70·9
3. Petroleum ether ..	—	80-100	69·5	61·0
4. Pyridine	0·903	115·3	75·0	74·3
5. Diacetone alcohol ..	0·931	164-166	52·5	52·5
6. Dekalin	0·934	188-190	73·8	58·1
7. Cottonseed oil	0·917	—	79·4	85·1

either surface, and scarcely more than half in the case of diacetone alcohol. The recovery was not found to be simply related to the boiling-point (or volatility) of the solvent, because benzene, pyridine and dekalin all afforded the same percentage recovery, although their boiling-points range over more than 100° C. (Table I).

2. *The effect of the nature of the solvent, or of the emulsifying agent used in the preparation of the emulsion, on the recovery of DDT.*

Emulsions containing 1 per cent. DDT were prepared, using four solvents and four emulsifying agents. The percentage recoveries of DDT from leaves treated with these emulsions are set out in Table II.

Emulsions prepared with soap, MB320 or Triton X-100, wetted surfaces easily and were readily spread upon either leaf-surface. Fixanol, on the other hand, imparted a repellent quality so that neither glass nor leaves were readily wetted by emulsions containing this emulsifying agent. For each preparation, the quantity of solvent used was minimal for solution of the DDT, but the quantity of emulsifying agent was adequate to give a stable emulsion for at least 24 hours ; cottonseed oil gave the poorest emulsion, regardless of emulsifying agent.

No scorching was seen when any of the emulsions were applied to the upper leaf-surface, but this form of damage always appeared when emulsions other than those containing cottonseed oil were applied to the lower surface. Crystals of DDT formed on either surface as the emulsions dried, again with the exception of cottonseed oil emulsions.

The amount of DDT recovered from the lower surface after application of cottonseed oil emulsions was the same as for a solution of DDT in this oil, but somewhat more was recovered from the upper surface. When any of the three other solvents were used, much more DDT was recovered from either surface from emulsions than from solutions, implying much less penetration. However, complete recovery was never attained.

Table II shows that the nature of the emulsifying agent has no influence on the amount of DDT recoverable. The nature of the solvent may have some influence, but no clear-cut differences in recovery appeared ; this was also found when solutions were applied (Table I), when even cottonseed oil failed to give a significantly greater recovery than did *n*-hexane from the upper leaf surface.

The differences in recovery between upper and lower surfaces were considerable when solutions were applied in solvents 1, 2, 3 or 6, but negligible in solvents 4 and 5,

TABLE II.

Percentage recovery of DDT applied in various emulsions.

Solvent	Emulsifying Agent									
	Sodium oleate, 0·5%		MB320, 0·025%		Fixanol, 0·025%		Triton X100, 0·5%		Average	
	Mean percentage DDT recovered									
	U.S.	L.S.	U.S.	L.S.	U.S.	L.S.	U.S.	L.S.	U.S.	L.S.
Benzene, 3·0 per cent.	88·4	85·3	92·9	81·3	88·3	89·6	90·7	84·0	90·1	85·1
Petroleum ether, 30·0 per cent. (Boiling point 80-100° C.)	92·3	94·9	92·8	91·6	92·4	89·3	88·1	91·1	91·4	91·7
Dekalin, 9·0 per cent.	85·0	86·6	83·6	77·6	85·6	84·3	87·7	93·2	85·5	85·4
Cottonseed oil, 12·0 per cent.	83·1	84·8	88·5	83·0	86·3	86·3	85·9	88·9	85·9	85·0
Average	87·2	87·9	89·5	83·1	88·2	87·4	88·1	88·6	—	—

U.S. = Upper surface.
L.S. = Lower surface.

and reversed in cottonseed oil compared with the rest. After applying emulsions, the recovery was more nearly the same from each of the two surfaces and there is no evidence that any solvent (except perhaps benzene) or any emulsifying agent (except perhaps MB320) influenced the difference. It would not appear that much DDT is lost by entry of solution or emulsion through stomata.

3. *The effect of the concentration of solvent used in the preparation of emulsions on the recovery of the DDT.*

Benzene was employed for this experiment because emulsions can be prepared containing up to 99 per cent. of this solvent. The emulsifying agent chosen was sodium oleate at 0·5 per cent., and the DDT content was 1 per cent. Concentrations of benzene ranged from 2 to 95 per cent., but the viscosity was inconveniently great at the highest concentrations; these concentrations and the percentage recoveries of DDT from both leaf-surfaces are set out in Table III.

TABLE III.

Percentage recovery of DDT applied in emulsions containing various amounts of benzene.

Benzene per cent.	Mean percentage DDT recovered	
	Upper surface	Lower surface
2·0	95·7	95·7
6·0	78·7	79·4
25·0	79·4	70·9
50·0	87·2	85·1
75·0	85·1	85·1
95·0	88·3	83·0
Benzene solution	74·8	70·9

The highest rate of recovery for either surface is associated with a minimum of benzene in the emulsion applied. The rates fall off sharply up to 25 per cent. benzene, but thereafter rise again to a fairly constant value, from 50 to 95 per cent. benzene, that is still below the value for the 2 per cent. benzene emulsion; the recoveries from the lower surface tended to be slightly lower than from the upper surface. The recoveries from the 25 per cent. benzene emulsion were very similar to those from a benzene solution; the higher recoveries, and hence poorer penetration, associated with emulsions containing 50 to 95 per cent. benzene were probably related to the increasing viscosities of these emulsions. It would appear advantageous to use a minimum of solvent in preparing DDT emulsions for use as contact insecticides, at least when soap is used as the emulsifier.

4. *The effect of the concentration of DDT, in the solution or emulsion deposited, upon the recovery of DDT.*

The experiments recorded under previous headings were all carried out with formulations containing 1 per cent. DDT. Two lower concentrations, 0·7 and 0·4 per cent., were also used in solutions and emulsions. The solvent, benzene, was used at 3 per cent., plus 0·5 per cent. sodium oleate, in the emulsions. Average recovery

figures, from two to four determinations in each case, are presented in Table IV. Besides the lower recovery from application of solution than from that of emulsion or from lower surface than from upper surface, already reported above, there is clearly greater proportionate loss as the amount of DDT is reduced in either formulation. This can be interpreted as showing that a greater proportion of DDT enters the leaf, especially the lower surface, from weak formulations than from strong, especially from solutions.

TABLE IV.

Percentage recovery of DDT applied in solutions or emulsions containing various amounts of DDT.

Percentage DDT in solution or emulsion	Average percentage recovery of DDT			
	Solution		Emulsion	
	Upper surface	Lower surface	Upper surface	Lower surface
1·0	74·8	70·9	88·4	85·3
0·7	64·8	49·6	85·8	70·7
0·4	49·7	35·5	71·3	78·2

5. *The correlation of chemical estimation of DDT residues with biological evaluation of washed leaves.*

The residual toxicity of a DDT-treated surface after washing off the deposit can be regarded as a measure of the effectiveness of that washing. Batches of the test insect were confined on areas of apple leaf (upper surface) which had been treated with 1 per cent. solutions or emulsions of DDT (solvent, benzene) at the rate of 5 mg. per 100 sq. cm., left for 24 hours, then washed with 3, 6 or 9 ml. benzene, and finally air-dried. The washings were analysed for DDT, and the results are compared with the bio-assay data in Table V.

TABLE V.

Recovery of DDT, 24 hours after deposition from 1 per cent. benzene solution or emulsion, by washing with varying amounts of benzene, compared with the toxicity of the washed surfaces to Tribolium confusum.

Volume benzene used for washing	Average percentage DDT recovered		Mortality of insects on washed leaves	
	Solution	Emulsion	Solution	Emulsion
3 ml.	65·3	66·7	3/53	1/59
6 ml.	58·9	59·6	4/59	1/48
9 ml.	68·2	64·6	3/46	3/60

Two facts emerge from these results : (*a*) the mortalities are negligible compared with that, 100 per cent., caused by the DDT on comparable unwashed leaves ;

(*b*) increasing the volume of wash-fluid from 3 ml. to 9 ml. removed no further DDT, as judged by chemical analysis or bio-assay. The method of washing employed was therefore adequate to remove the DDT available for contact action against this insect.

That this simpler form of DDT-removal gives much lower recovery values than does the standard shaking technique described above, without affecting the subsequent toxicity of the leaf, is shown by tests carried out with DDT in 1 per cent. solutions or emulsions using benzene and dekalin as solvents, or as a 1 per cent. suspension prepared from a diacetone alcohol solution. Sodium oleate, 0·5 per cent. was used as emulsifier, and 6 ml. benzene was used to strip the leaves (upper surface only). The results are set out in Table VI.

Even with the dekalin solution, where only 23·6 per cent. of the DDT applied was removed by stripping and more than 75 per cent. remained in the leaf, there was an insignificant mortality of the test insect up to six days' exposure. The insecticide not removed by simple washing with solvent must therefore be very inaccessible and useless for contact action. The much greater amount removed by the shaking technique indicates the extent to which solutions of DDT must penetrate the leaf as compared with suspensions and emulsions.

TABLE VI.

Recovery of DDT, deposited as solution, emulsion or suspension, by two methods of removal, and the toxicity of the final leaf surfaces to T. confusum.

Formulation	Average percentage DDT recovered		Mortality of insects on washed leaves
	Stripping	Shaking	
Benzene solution	51·7	74·8	2/81
10 per cent. benzene emulsion	68·5	90·2	0/75
Dekalin solution	23·6	73·8	3/77
10 per cent. dekalin emulsion	66·9	85·5	0/74
25 per cent. diacetone alcohol suspension ..	82·1	91·0	—

6. *The toxicity to* T. confusum *of DDT deposits on glass and leaves and the correlation with chemical estimations.*

The chemical assays so far reported were made on deposits from formulations containing 1 per cent. DDT, giving 5 mg. DDT per 100 sq. cm. As this concentration always leads to 100 per cent. mortality when *T. confusum* adults are put on the deposit for six days, five lower concentrations, 0·08 to 0·005 per cent., were employed to obtain dosage-mortality relationships and hence LD_{50} values.

Two separate series of experiments were conducted. In the first, the mortalities were recorded for a benzene emulsion on glass and on leaf and for a pyridine suspension and a benzene solution on leaf, Table VII. The regression lines for these preparations shown in Fig. 1 are depicted as straight but that for solution-on-leaf is based on only three points and a value for the slope would be very unreliable. The suspension-on-leaf and emulsion-on-leaf lines may well be parallel to each other, the latter being less effective than the other in strict accordance with the relative chemical recovery

values from these two types of formulation, given in Table VI. The line for emulsion-on-glass was certainly not parallel to that for this formulation on leaf ($P<0.001$) and this difference presumably reflects the effect described under section 4 above, namely, the relatively greater loss of DDT by penetration from weak than from strong formulations. If this effect be real, then the lines for suspension-on-leaf and emulsion-on-leaf should be curved. Further evidence in favour of this view is that, as drawn, these lines cross that for emulsion-on-glass, indicating greater toxicity above approximately the LD_{90} values. As this is highly improbable, it seems that either the emulsion-on-glass line or the two leaf lines must be curved.

In the second series of experiments, a benzene emulsion was compared on glass and on leaf and a dekalin emulsion was also tested on leaf. The results of two experiments, shown in Table VII, provided the regression lines shown in Fig. 2. Although the absolute mortalities on the two occasions differ, the relative values are the same, yielding parallel lines for both benzene emulsion-on-leaf tests and for both dekalin emulsion-on-leaf tests. It would appear, however, that not only is there increasing penetration of DDT in both instances as concentration falls, giving lines of greater slope than for emulsion-on-glass (as in Fig. 1), but also penetration from dekalin emulsions increases with fall of DDT concentration more rapidly than it does from benzene emulsions, giving a line with greater slope.

TABLE VII.

Mortalities of T. confusum *adults for five concentrations of DDT in various formulations on glass and leaf.*

Series	Formulation	Surface	DDT concentration × 10^3				
			80	40	20	10	5
			Percentage mortality (C = 0)				
I	Benzene emulsion	Glass	94·4	80·9	68·9	26·7	3·4
	,, ,,	Leaf	95·6	68·2	22·0	(1·1)	(0·0)
	,, solution	,,	58·9	54·4	1·1	(0·0)	(0·0)
	Pyridine suspension	,,	97·8	86·7	26·7	6·7	(1·1)
II, 1	Benzene emulsion	Leaf	86·0	26·0	6·2	(0·0)	(0·0)
	Dekalin ,,	,,	82·0	36·0	16·0	(0·0)	(0·0)
2	Benzene ,,	,,	75·3	33·3	4·5	(1·1)	(0·0)
	Dekalin ,,	,,	76·7	15·6	2·3	(0·0)	(3·3)
	Benzene ,,	Glass	88·3	51·7	31·7	13·3	(0·0)

Figures in brackets were ignored when regression lines were calculated.

7. *The rate of loss of DDT, related to toxicity to* T. confusum, *from leaves under orchard conditions.*

Two series of experiments were carried out using undetached leaves. In the first series, 50 μg. DDT per sq. cm. was applied in the form of a 1 per cent. emulsion, containing 3 per cent. benzene and 0·5 per cent. sodium oleate, on different leaves at intervals. The leaves were then detached, some being subjected to washing (6 ml. benzene) and subsequent bio-assay and others used for bio-assay without washing. The ages of the deposits at the time of assay were 1, 7, 13, 21 and 28

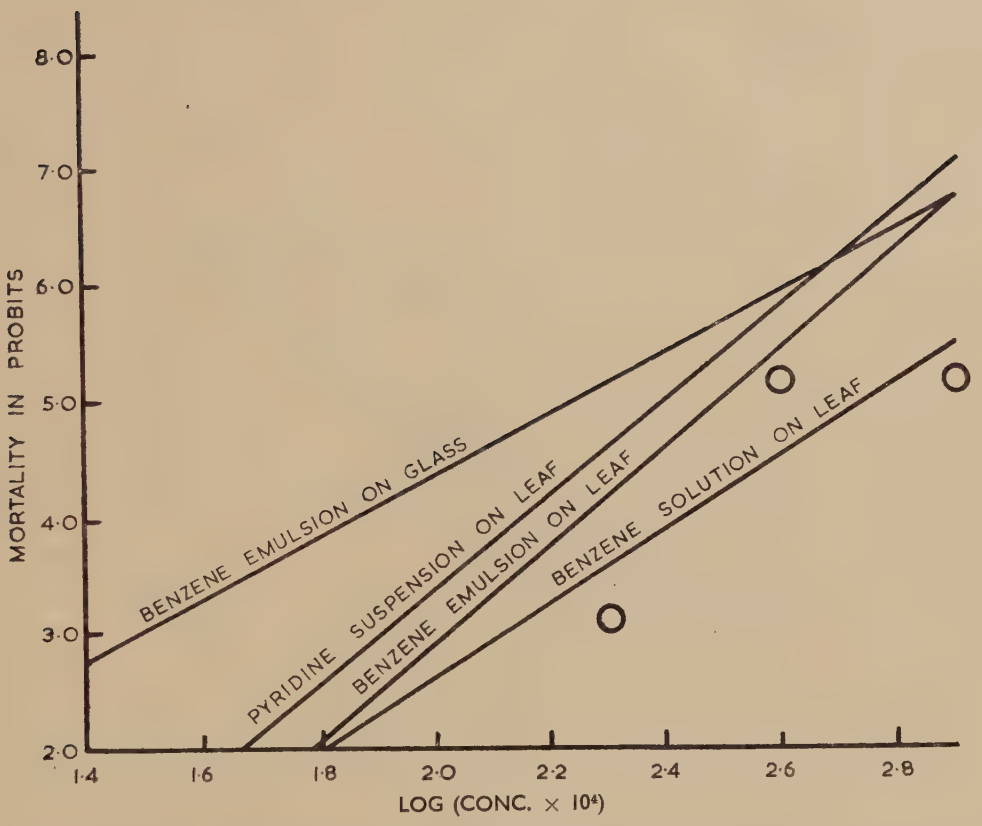

FIG. 1.

Dosage-mortality relationships for DDT formulations using adults of *Tribolium confusum* Duv.
o = points from which solution-on-leaf line was derived.

Formulation	*y*	χ^2	LD_{50}
Benzene emulsion on glass	2·686x + 1·695	6·92	0·018%
,, ,, on leaf	4·278x − 1·385	0·00	0·031%
,, solution ,,	3·244x − 0·637	32·25	0·053%
Pyridine suspension ,,	4·079x − 0·678	11·77	0·023%

days respectively. Rain following closely on application appeared to invalidate the results for the 7-day-old deposits only. A total of 1·67 in. rain fell during the 28-day period, of which 1 in. fell in one 24-hour period, the rest being well distributed throughout the month. Maximum temperatures varied from 61-84° F., averaging 72° F. The rate of loss of DDT as determined chemically is given in Fig. 3, from which it is seen that the rate is proportional to the logarithm of the time. Even after 28 days, there remained 19 μg. per sq. cm., and it is therefore not surprising that the mortalities of *T. confusum* on deposits of all ages in the series were not significantly less than 100 per cent. No insects died when placed on washed leaves, indicating complete removal of available DDT. There was no significant loss in the first 24 hours as compared with leaves similarly treated, but detached and stored in the laboratory ; in both cases one-third of the DDT had become unavailable.

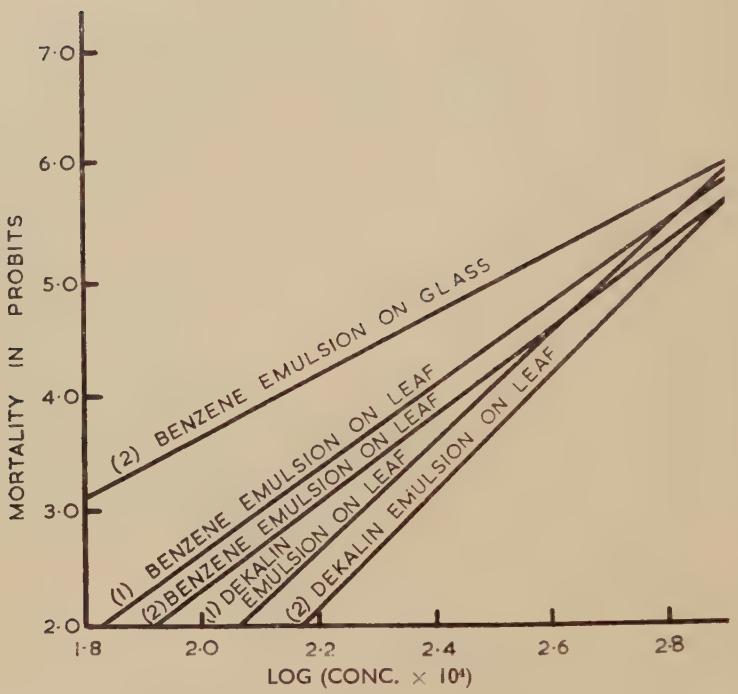

FIG. 2.

Dosage-mortality relationships for DDT emulsions using adults of *Tribolium confusum* Duv. Two series.

Series	*Solvent*	*Surface*	*y*	χ^2	LD_{50}
1	Benzene	Leaf	3·568x − 0·911	0·87	0·045%
1	Dekalin	Leaf	4·652x − 2·899	2·73	0·050%
2	Benzene	Glass	2·582x + 1·109	3·66	0·032%
2	Benzene	Leaf	3·675x − 1·323	0·00	0·053%
2	Dekalin	Leaf	4·938x − 3·748	2·33	0·060%

In the second series of experiments on weathering, emulsions containing 1 per cent. benzene and 0·05 per cent. *cyclo*-hexylamine dodecyl sulphate were prepared to provide 0·2 to 0·0125 per cent. DDT. Leaves measuring about 20 sq. cm. were dipped in the appropriate emulsion for 10 seconds and then allowed to drain dry. By measuring the volume of emulsion removed by the leaves of each treatment, it was possible to get an average value for the DDT present per sq. cm. The 0·2 per cent. emulsion was calculated to have given a deposit of 12 μg. per sq. cm., and the others 6·0, 3·0, 1·5 and 0·75 μg. respectively. The total period was 22 days, with the maximum temperatures between 68 and 86° F., averaging higher than in the first series; rainfall was only 0·05 in. altogether. The loss of toxicity was estimated as described above with *T. confusum*, and the results are set out in Table VIII. The time mortality line in Fig. 4 indicates that the rate of loss is proportional to the logarithm of time.

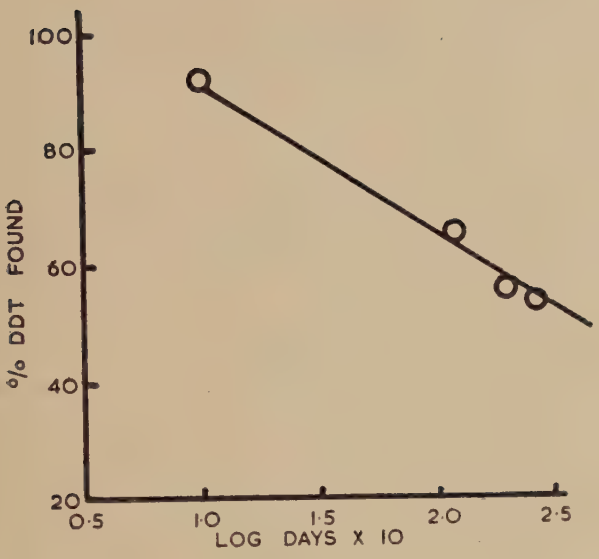

FIG. 3.
The rate of loss of DDT deposits.

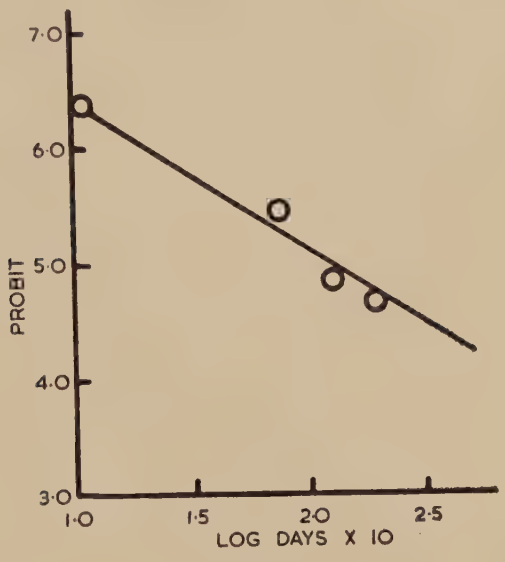

FIG. 4.
Relation between age of DDT deposits and their toxicity (0·2% conc. DDT).

From a consideration of section 4 above, it would be expected that the maximum deposit of 12 μg. from 0·2 per cent. emulsions would have dwindled to little more than 6 μg. available DDT after 24 hours ; this would be unlikely to cause 100 per cent. mortality of *T. confusum* and, of course, the lower emulsion concentrations would yield even lower available deposits. This is borne out by the results in Table VIII, which also show that the lowest two concentrations give deposits which are non-toxic after a week. Only the highest concentration emulsion gives deposits toxic to this insect after a fortnight. Of course, some orchard insects must be much more susceptible to DDT than is *T. confusum* but, in these experiments, deposits were likely to

TABLE VIII.

Loss of toxicity of DDT deposits on leaves in the orchard to T. confusum *with lapse of time.*

Concentration of DDT in emulsion per cent.	Age of deposit in days			
	1	8	14	22
	Proportion of insects killed			
0·2	80/87	60/92	40/90	34/90
0·1	77/88	18/90	0/92	0/88
0·05	59/90	23/89	0/90	0/89
0·025	49/93	1/91	0/90	0/90
0·0125	60/90	2/91	0/90	0/90

have been much more even than in normal spray practice, and the insects were confined to treated areas which is also a more rigorous procedure than under normal field conditions.

SUMMARY.

1. The strong absorption of DDT by apple leaves has been established. Prolonged shaking with benzene permitted almost total recovery of DDT applied to leaves as a solution, emulsion or suspension, but stripping with benzene gave only partial recovery. The amount recovered by stripping was most from suspension-treated leaves, and least from solution-treated.

2. The nature of the solvent used in solutions affects the recovery, but this effect is not related to boiling-point. No such effect seems to occur with emulsions.

3. The nature of the emulsifying agent would not appear to be important.

4. Emulsions containing high or very low amounts of organic solvent leave larger deposits on the surface than do emulsions containing intermediate percentages. This presumably is due to the opposing effects of evaporation-rate and viscosity.

5. The proportion of DDT remaining on the leaf-surface varies with the concentration of DDT in the formulation applied. The amount remaining from solutions falls more rapidly with the concentration applied than from emulsions, especially on the lower surface.

6. Adults of *Tribolium confusum* Duv. are not affected by the DDT not removed from leaves by simple stripping.

7. Weathering of leaf-deposits under summer conditions indicated that deposits of less than 12 μg. per sq. cm. would become non-toxic to *T. confusum* after a week, but that deposits of 50 μg. per sq. cm., after 28 days exposure, still caused complete kill of this insect. The rate of loss by weathering was proportional to the logarithm of the time of exposure.

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The author is greatly indebted to Prof. H. Shaw and Prof. R. L. Wain who supervised the studies herein reported, and to Dr. A. H. M. Kirby and Prof. Wain for assistance in preparing the manuscript. He would also like to thank Mr. R. G. Davies for much guidance in the bio-assay work, and Dr. S. C. Pearce for statistical examination of the results.

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LOW TEMPERATURE INJURY TO FRUIT BLOSSOM

IV. FURTHER EXPERIMENTS ON WATER-SPRINKLING AS AN ANTI-FROST MEASURE

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MANY accounts have been given of protecting plants from frost damage by sprinkling them with water during a frost, but data on the temperature rise provided by a given amount of water, under specified conditions, are still scanty.

Kessler (1936) maintained plant temperatures at 30·2° F. to 31·1° F. (−1·0° C. to −0·5° C.) during a frost of 19·4° F. to 21·2° F. (−7° C. to −6° C.). Mercanton (1939) protected plants during a frost of 21·2° F. to 24·9° F. (−6° C. to −4° C.), and Crowley (1925-6) protected blueberries in frosts of 25° F. (−3·9° C.). These reports, however, do not give details of the rates of precipitation used.

Both Weger (1947), who applied water at a rate of 1 to 2 mm. hr., and Wanke (1951), who applied water at a rate of 3 to 4 mm./hr., claimed that these rates of precipitation gave protection in most frosts. Jeffree (1950) claimed that a rate of application of one-tenth of an inch (2·5 mm.) per hour would give protection in " normal " spring frosts, and suggested that over a large area this rate of precipitation should protect plants from 16° F. of frost (−8·9° C.).

Koeppner (1949) protected plants in a frost of 21·2° F. (−6° C.), lasting 15 hours, with rates of precipitation not in excess of 4 mm./hr. Witte (1951 and 1952) came to the conclusion that a " rainfall " of 1·5 mm. hr. was essential and also quite adequate to control ground frosts down to 20·1° F. (−6·6° C.).

Kessler and Kaempfert (1940) protected plants in frosts of 26·6° F. (−3·0° C.) and 19·4° F. (−7·0° C.). They suggested that rates of application of 4 to 5 and 6 mm./hr. respectively were more than was required, and that 1 to 2 mm. hr. seemed to be sufficient.

In discussing conditions associated with the sprinkling of plants with water during frosts, Hansen (1951) stated that water must be applied until the ice has completely disappeared. Roberts (1950), reporting on three years' observations on sprinkling strawberries, claimed that these plants had been protected from frosts as severe as 12° F., 13° F. and 15° F. (−11·1 C., −10·6° C. and −9·4° C.) respectively. He reported that strawberry beds were often watered in sections, depending upon the apparatus available, and that each section might be watered more than once during the night.

Rogers and Modlibowska (1950) maintained the temperature of apple blossom at between 31° F. and 32° F. (−0·6° C. and 0° C.), during a spring frost when the air temperature, as measured by thermocouple, fell to 26·6° F. (−3·0° C.), with an average rate of precipitation of 4·2 mm./hr. They stopped sprinkling when the air temperature returned to 32° F. (0° C.), but stressed the necessity for continuing sprinkling throughout the period of the frost.

The present paper describes further experiments designed to show the relationship between the rate of precipitation and the rise in temperature, for varying degrees of frost, the minimum safe rate of precipitation required to afford protection from given degrees of frost, and the performance of various types of sprinkler.

In all, twenty-six laboratory experiments and thirty-five field experiments were carried out on these problems in 1950, 1951 and 1952. On account of limitations of space, only seven representative experiments have been selected for description in detail, but the others all added their quota of support to the conclusions of this paper.

Instruments and equipment.

The measurement of temperature.

Minimum thermometers of the Meteorological Office type and bimetallic thermographs were used for the measurement of air temperatures in the field. The calibration of these instruments was checked at intervals of about six months.

Copper-constantan thermocouples, 26 s.w.g., were used for the measurement of air temperatures and the temperature of such robust tissues as the stems and petioles of potato and tomato plants. Fine thermocouples, 40 s.w.g., inserted in the tissues (Slater, 1953), were used for the measurement of bud and blossom temperatures. The thermocouples were variously attached to a manual potentiometer calibrated to read to 0·1° C., a manual potentiometer calibrated to read in microvolts, a Foster 6-point automatic recording galvanometer calibrated to read to 0·2° C. and used in conjunction with a Tinsley amplifier, a Kent single point continuous recording potentiometer and an Electroflo 4-point recording galvanometer both used in conjunction with a Sunvic D.C. amplifier and both having an adjustable range, and a Cambridge 2-point clockwork recording galvanometer.

For laboratory experiments the recording instruments were installed in a constant temperature room adjoining the refrigeration room. During field experiments the recording instruments were housed in a caravan especially fitted out for the purpose.

Humidity.

Wet and dry bulb thermometers were installed in a Stevenson screen, a hair hygrograph was placed on the ground near the screen, and a whirling psychrometer was available for use as required.

Wind speed.

A Sheppard cup anemometer, sensitive to wind speeds of 1 ft./sec. was used at a height of 6 ft. 6 in. in the experimental area, and a Dynes anemobiograph, recording at a height of 35 ft., was about half a mile away.

Rain gauges.

In the field, 7 lb. tins were used and in some laboratory tests 3 × 1-in. glass specimen tubes were used. It was found that the layer of ice which formed on the walls of the containers allowed siphoning of the water to take place, especially during thawing, causing serious errors of measurement unless precautions were taken. This difficulty was overcome by soldering a lip to each can, or by placing a flared rubber ring on each specimen tube (Fig. 1). The effect of this was to maintain an air gap in the tube of ice.

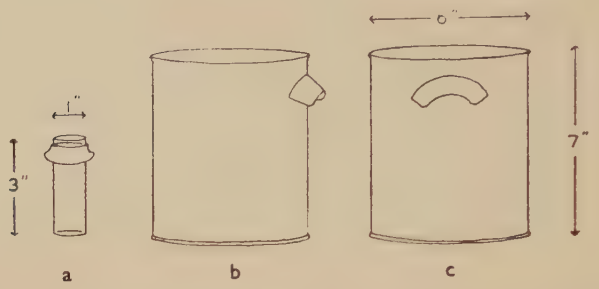

FIG. 1.
(*a*) Rubber ring on specimen tube, to prevent loss of water by siphoning;
(*b*) and (*c*) two views of measuring-tins used in the field, showing construction of lip to stop siphoning.

Sprinklers.

In field experiments, five different types of sprinkler were tested. They were :

Type A. Small reaction-operated sprinklers.
Type B. Impact-operated rotary spray heads.
Type C. Oscillating spray lines.
Type D. Large rotary rainers.
Type E. Fine mist sprinklers.

Further details are given in the individual experiments.

LABORATORY EXPERIMENTS.

Laboratory tests of spraying and of controlled water-dropping were made in the refrigeration room.

SPRAYING.

Materials and methods.

Discs of tissue from a potato tuber were used as a standard simple tissue which would show frost damage by a colour change. Five potato discs, about 1 cm. diameter and 1 cm. thick, were supported on wire forks, and into each disc was inserted a fine wire thermocouple. The thermocouples were connected either to the Foster recorder or to the manual potentiometer. Specimen tube " rain " gauges were supported in wire holders as near to the potato discs as possible, and each unit of one disc, with thermocouple, and one specimen tube was fixed in a clamp projecting at a height of about 18 in. from a retort stand.

Tap water, stored in a drum in an adjacent room at a temperature of about 42° F. (5·6° C.), was pumped at constant pressure through a spray nozzle.

The temperature of the air in the room was lowered in steps of approximately 1·8° F. (1·0° C.), the fall between each step being fairly rapid, and the duration of each step being about 20 minutes.

Results.

The records, from both the manual potentiometer and the Foster recorder, show that ice formed on all the sprinkled potato discs when the air temperature was about 28·4° F. (—2·0° C.).

From Table I it can be seen that a rate of precipitation of 2·9 mm./hr. kept the potato disc at the safe level of 29·0° F. (—0·6° C.) when the air temperature was 22·8° F. (—5·1° C.). For rates of precipitation of 5·4 mm./hr., and over, much of the warming effect is probably due to the temperature of the water rather than to the heat liberated by ice formation, especially when temperatures above 32° F. (0° C.) are recorded. Also, the fact that these rates of precipitation tend to maintain the potato discs at a constant temperature, irrespective of the air temperature (within the limits of this experiment), suggests that they are higher than those needed to achieve protection

Table I.

Temperatures maintained by various rates of precipitation, at various room temperatures.

Rate of precipitation (mm./hr.)	Air temperature in room (° F.)			
	28·4	26·6	25·3	22·8
	Temperature of potato disc (° F.)			
2·9	31·0	31·0	30·6	29·0
5·4	30·8	30·8	30·8	30·8
6·2	31·3	31·3	31·3	31·3
8·4	32·9	32·5	32·7	32·0

Controlled dropping.

Materials and methods.

Air-free water, at a temperature of about 34° F. (1·1° C.), was allowed to drop on to a potato disc, the rate of dropping being controlled by a tap. Two fine wire thermocouples, inserted in the disc, led respectively to the manual potentiometer and the Kent recorder. It was found that for a given setting of the tap the intervals between drops gradually increased. When the interval was about 10 min. the tap was reset and the process repeated.

The temperature of the room was lowered quickly to 26·4° F. (—3·1° C.) and kept there for a period of 1 hr. It was then lowered to 20·0° F. (—6·2° C.) where it was maintained for about 40 min., after which the room was warmed up.

Results.

The results are presented in Fig. 2, in which the dropping rate is expressed as mm./hr. They show that the more severe the frost the greater the rate of precipitation required to maintain a given temperature, and that the lower the air temperature the greater the rise in the temperature of the disc produced by a given rate of precipitation. Hence the curves converge as the rate of precipitation increases. This suggests that the efficiency of sprinkling, in terms of heat transfer, increases (within limits) as the temperature falls ; this is probably due to a combination of several factors. At lower temperatures the water is more quickly frozen than at higher temperatures and consequently there is less run-off. Also, the more rapid the rate of freezing the smaller the loss of heat due to evaporation.

The shape of the curves is similar to that found in several experiments in the field, in which rate of precipitation could be compared with temperature rise. It is clear that the relationship is not one of simple proportion.

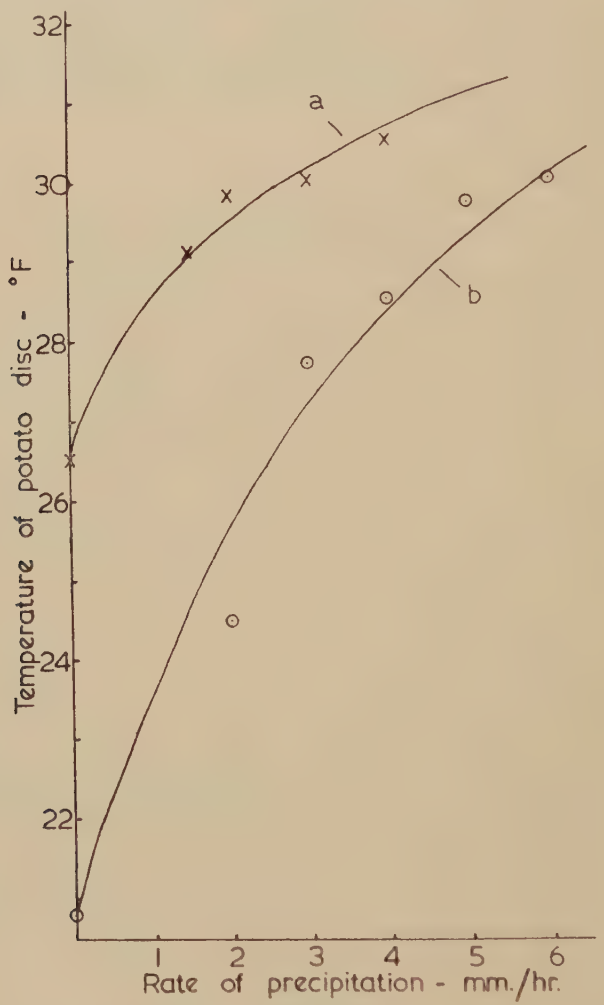

FIG. 2.

The warming effect of the freezing of drops of water on a potato disc;
(*a*) air temperature 26·4° F. (−3·1° C.),
(*b*) air temperature 20·9° F. (−6·2° C.).

FIELD EXPERIMENTS.

Of the thirty-five field experiments, twenty-six were carried out in the autumn and winter, and nine in the spring. It should be noted that conditions in the autumn and winter may differ in several ways from those in spring. The soil, for instance,

is warmer in the autumn and much colder in winter, than in spring. In the absence of severe spring frosts during the period under review, the winter work has proved very valuable; in fact, the information it has given corresponds well with that obtained in the few early spring frosts.

I. Winter sprinkling.

A series of experiments was carried out in an orchard of mature Cox's Orange Pippin apples during the winter of 1951 to 1952. The trees were spaced 24 ft. apart, and their branches just met (Fig. 3).

Materials and methods.

(i) *Sprinkling apparatus.* Six small overhead irrigation units (Type A) were used. These were reaction-operated rotary sprinklers, having a single arm of bent brass tubing (Fig. 3). With a jet size of $\frac{1}{8}$ in. and a pressure of 25 lb. per square inch, they gave an output of about 2 gallons per minute and covered a circle of 48 to 54 ft. diameter. The units were spaced at 48 ft. square, forming two rows of 3 units, placed midway between trees in alternate tree rows running north to south.

Each sprinkler was mounted at a height of 15 ft. on a mast of $\frac{3}{4}$-in. galvanized iron piping (Fig. 3). Water, taken from a main running near the orchard, was led through a pipeline of $1\frac{1}{4}$-in. quick-coupling steel piping to a distributor unit. From this unit six lengths of $\frac{3}{4}$-in. rubber or plastic hose were connected, one to each mast. A recording pressure gauge, normal pressure gauges and control taps were incorporated in the distributor unit.

" Rain " gauges were placed at varying distances from the sprinklers, care being taken to avoid their being sheltered by branches.

(ii) *Temperature measurement.* Minimum thermometers were set out at heights of 1 ft., 4 ft. 6 in.,* and 9 ft., in the sprinkled and control areas. A Stevenson screen in the control area contained a minimum thermometer (at a height of 4 ft. 6 in.*) wet and dry bulb thermometers, and a thermograph. A thermograph and a hygrograph were placed on the ground near to the screen.

Sets of three 26 s.w.g. thermocouples were mounted at heights of 4 ft. 6 in., 9 ft. and 25 ft. on two masts, one in the control area and the other in the sprinkled area equidistant from four sprinklers.

Fine wire thermocouples, either singly or in pairs, were run out to suitable points in the orchard. Single ones were inserted in buds at a height of 4 ft. 6 in., whilst, of the pairs, one of each pair was inserted in a bud at 4 ft. 6 in. and the other in a bud at 9 ft. Usually the selected buds at a height of 9 ft. were near to a minimum thermometer at the same height, and near to both, supported in a wire holder on a pole, was placed a " rain " gauge.

The recording instruments, which were installed in the caravan, included the manual potentiometer and the Electroflo and Cambridge recorders.

The Sheppard anemometer was set up on the headland flanking the orchard.

(iii) *Procedure.* As the air temperature approached 32° F. (0° C.) measurements of the temperature shown by all thermocouples connected to the manual potentiometer were taken at intervals of 10 min. When the temperature reached 32° F. (0° C.) sprinkling was started. Thermocouple readings were then taken on the

* Following discussion with the Meteorological Office, it was decided that the height of 4 ft. should be used for both screen and exposed thermometers, in experiments after 1952.

manual potentiometer at intervals of either 5 or 10 min., depending upon the number of thermocouples being used.

At hourly intervals records of the wind speed and direction and the wet and dry bulb temperatures were taken. A short inspection of the sprinklers and gauges was also carried out.

When the air temperature had returned to 32° F. (0° C.) sprinkling was stopped and thermocouple readings were continued until all showed a reading above the freezing point.

After the frost, records were made of the minimum temperatures shown by the thermometers, and of the quantity of water in the cans.

In one experiment (not here described in detail) sprinkling was not started until some time after the temperature had fallen below freezing and, in another, sprinkling was stopped before the air temperature had returned to 32° F. (0° C.).

Results.

In two of the experiments, carried out on 10th-11th December, 1951, and 29th-30th January, 1952, under radiation frost conditions (with complete calm recorded by the anemobiograph at 35 ft.) the screen minima were 21·8° F. (−5·6° C.) and 24·6° F. (−4·1° C.) respectively. In the former the katabatic wind was from the south with an average speed of 1·5 m.p.h. at a height of 6 ft. 6 in., and in the latter it varied between south and south-west with a speed of from 2·0 to 2·5 m.p.h.

The results, presented in Tables II and III, demonstrate the warming effect of sprinkling. In general, as the rate of precipitation increases so the temperature of the sprinkled object increases. There are, however, occasional anomalies, as can be seen from the records for thermometers at 1 ft. and 4 ft. 6 in. (in Table II) and buds at 4 ft. 6 in. (in Table III). No satisfactory explanation for these departures from the normal have so far been found, and they are not considered to occur so frequently as to invalidate the general principle.

The temperature of buds and thermometers situated in very lightly sprinkled areas, especially those midway between four sprinklers (Tables II and III), suggest that there is a warming effect even here. This is probably due to a heating effect from ice forming in the more heavily sprinkled areas. The records from the air thermocouples support the suggestion that this heating effect is due to heat transfer from the adjacent warmer areas.

It can be seen from the Tables that thermometers situated on the down-wind (north) side of the sprinkled area but not sprinkled, show, with one exception, a higher minimum temperature than the thermometers on the windward side of the area.

Comparing the minimum temperatures of unsprinkled (and unscreened) thermometers at 4 ft. 6 in., in the same region as the screen, with the screen minimum temperatures, it can be seen that they record temperatures ranging from 1·3° F. (0·7° C.) to 3·5° F. (1·9° C.) below those recorded in the screen. Similarly, the minimum temperatures recorded for buds at 4 ft. 6 in. range from 0·8° F. (0·4° C.) to 1·2° F. (0·7° C.) below those recorded in the screen.

Results from a large number of observations confirm these points, showing that unscreened minimum thermometers commonly record minima about 1° to 2° F. (0·6° to 1·1° C.) lower than in the screen, and buds and blossoms about 1·5° F. (0·8° C.) lower than in the screen.

Table II.

Minimum temperatures of thermometers and buds receiving different rates of precipitation, during a radiation frost when the minimum temperature in the screen was 21·9° F. (−5·6° C.).

Rate of precipitation (cans on ground) (mm./hr.)	Minimum temperature (° F.) at the heights indicated.						Remarks
	Thermometers			Thermocouples			
				Air	In buds		
	1 ft.	4 ft. 6 in.	9 ft.	4 ft. 6 in.	4 ft. 6 in.	9 ft.	
nil	19·0	19·6	—	20·7	20·7	20·8	Controls (on S. side of area sprinkled).
nil	19·4	19·7	—	—	20·8	19·9	Near controls.
nil	—	19·6	19·6	—	—	—	On S. side of sprinkled area.
nil	19·2	20·1	—	—	—	—	On N. side of sprinkled area.
nil	19·2	20·3	—	—	—	—	
nil	—	—	21·0	—	—	—	On W. side of sprinkled area.
nil	—	—	—	21·6	22·3	21·2	Situated midway between four sprinklers.
tr.	19·9	20·2	—	—	—	—	
0·1	20·0	21·1	—	—	21·9	—	
2·0	23·1	23·0	—	—	24·2	—	
2·0	—	23·0	23·6	—	23·0	22·9	
2·4	—	—	23·0	—	22·5	22·5	
3·0	—	23·0	—	—	—	—	
3·4	23·9	24·0	—	—	—	—	
3·6	22·9	23·4	—	—	—	—	

It will be noticed, especially in Table III, that for a given rate of precipitation the minimum temperature of a bud is higher than that of a minimum thermometer. If, however, comparison is made between the rise in temperature produced in each case for the given rate of precipitation, then the results given in Table IV (compiled from smoothed curves based on Table III) are obtained. Here it can be seen that the rise in temperature produced by a given rate of precipitation is greater for a minimum thermometer than for a bud. This is probably due to a combination of differences in surface area, thermal conductivity and specific heat.

Despite every precaution it would appear from Table III that rates of precipitation recorded at a height of 9 ft. are in excess of those recorded on the ground, suggesting that there is some shelter, probably from branches, to the cans placed on the ground.

During these long winter frosts the layer of ice formed on the sprinkled branches became quite thick (often about 2 cm.). The weight of ice caused the branches to bend, but did not break them (Fig. 3).

TABLE III.

Comparison of the minimum temperatures of thermometers and buds with the corresponding rates of precipitation during a radiation frost, when the minimum temperature in the screen was 24·6° F. (−4·1° C.).

Rate of precipitation (mm./hr.)		Minimum temperature (° F.) at the height indicated							
		Thermometers			Thermocouples				
					Air			In buds	
Cans on ground	Cans at height of 9 ft.	1 ft.	4 ft. 6 in.	9 ft.	4 ft. 6 in.	9 ft.	25 ft.	4 ft. 6 in.	9 ft.
nil (a)	nil	22·2	21·9	—	25·2	—	26·8	23·8	25·0
nil (b)	nil	—	23·2	—	—	—	—	—	—
nil (c)	nil	21·1	22·8	—	—	—	—	—	—
0·8 (d)	0·4	—	24·3	24·5	25·2	26·6	26·8	25·4	27·3
0·9	—	22·1	23·9	—	—	—	—	—	—
1·3	2·1	—	25·2	25·3	—	—	—	26·8	26·6
1·4	2·3	25·2	25·0	27·0	—	—	—	26·3	27·3
1·5	—	—	—	—	—	—	—	—	28·4
2·4	—	25·8	26·3	—	—	—	—	—	—
2·6	—	—	—	—	—	—	—	27·5	28·6
3·1	3·2	—	—	27·2	—	—	—	27·0	28·9

NOTES. (a) Controls (on S. side of sprinkled area).
(b) Near controls.
(c) On N. side of sprinkled area.
(d) Situated midway between four sprinklers.

TABLE IV.

Comparison of rate of precipitation and rise in temperature produced in thermometers and buds in a screen frost of 24·6° F. (−4·1° C.). The values are obtained from a smoothed curve based on the results given in Table III.

	Temperature rise (° F.) for a given rate of precipitation				
Precipitation (mm./hr.)	1·0	1·5	2·0	2·5	3·0
Thermometers	2·1	2·7	3·3	3·8	4·2
Buds	2·0	2·6	3·0	3·4	3·7

II. Sprinkling in the early spring.

An experiment, which included a rough comparison of different types of sprinkler, was carried out on a ley on the south side of Bradbourne lake on the night of 14th-15th March, 1952.

Materials and methods.

(i) *Sprinkling apparatus.* Four different sprinklers were compared, viz.: (1) the Type A reaction-operated sprinkler which has already been described (p. 131), (2) a similar sprinkler, made of plastic tubing, (3) an impact-operated rotary spray head (Type B), of the hydraulically balanced type which, with a main jet of $\frac{1}{4}$ in. and a pressure of 35 lb. per sq. in., gave an output of nearly 5 gal. per min., covered a circle of about 80 ft. diameter and, in this experiment, rotated once in 48 sec., and (4) an oscillating spray line (Type C), 45 ft. in length, with nozzles of $\frac{1}{16}$ in. spaced at intervals of 2 ft. and operated at a pressure of 35 lb. per sq. in., which covered a rectangle approximately 45 ft. × 54 ft. and completed one oscillation in 56 sec. (this is slower than usual).

Water was pumped from the lake into a $1\frac{1}{4}$-in. portable pipe line, from which branch lines or hoses were taken to the sprinklers. A pressure gauge and a control tap were placed in each branch line.

The two Type A units were mounted independently at a height of 5 ft., the rotary spray head (Type B), on its own mounting, was at a height of 4 ft. 6 in., and the oscillating spray line (Type C), supported on its own stands, was at a height of 15 in. from the ground.

" Rain " gauges were placed at regular intervals from each sprinkler.

(ii) *Plant material.* Five cherry trees (variety Frogmore) in full blossom, grown in pots and brought on in the glasshouse, were disposed one in the sprinkled area of each sprinkler, and one as control. Eight potato plants, similarly grown, were placed in pre-selected positions with respect to the sprinklers. Records of damage were made after the experiment.

(iii) *Instruments.* Minimum thermometers were set out at heights of 1 ft. and 4 ft. 6 in. respectively, some to each sprinkler, two controls and one in the screen. Thermocouples, supported on canes, were inserted into either flowers on the cherry trees or the petioles of leaves of the potato plants. The recording instruments, housed in the caravan, included the manual potentiometer, and the Kent and Cambridge recorders. Two thermographs, a hygrograph and the anemometer were set out, as in previous experiments.

Results.

The minimum temperature recorded in the screen was 25·5° F. (−3·7° C.). The anemometer records showed that a breeze of 2-4 m.p.h. east-north-east in the early part of the night fell to a calm about 4.30 a.m. G.M.T., after which a south-east breeze sprang up at 6.20 a.m. just before dawn. Similar records were obtained from the anemobiograph. Sprinkling was started at 1.45 a.m. and ended at 7 a.m.

Table V shows the rise in temperature given by different rates of sprinkling. As these were single, isolated, sprinklers, the rise obtained towards the edge of their spread was less than is found with a battery of sprinklers; in fact, in the very lightly sprinkled areas, where water probably fell only at long intervals, slightly lower temperatures were recorded than in the control area. This was probably due to evaporation.

TABLE V.

Rise in temperature produced by various rates of precipitation and by different sprinklers.

Type of sprinkler	A. Small rotary		B. Rotary spray head					C. Oscillating spray line	
	Metal	Plastic							
Rate of precipitation (mm./hr.)	2·6	2·5	0·1	1·9	2·9	3·4	3·4	1·9	4·5
Rise in temperature produced at 1 ft. (° F.) ..	3·7	3·1	−1·2	1·3	3·6	6·0	5·4	2·7	7·5
Rise in temperature produced at 4 ft. 6 in. (° F.) ..	2·1	—	−0·8	2·6	4·2	4·7	4·0	1·2	5·8

Damage to cherries was estimated on the basis of the degree of discoloration of the styles. All the flowers on each tree were examined and recorded. The results, summarized in Table VI show that sprinkling at a sufficient rate raised the temperature of the blossoms and had a protective effect. It should be noted that these plants, forced in a glasshouse, were more susceptible to frost damage than plants accustomed to field conditions.

TABLE VI.

*Minimum temperatures of, and damage to, flowers of cherry trees.**

Sprinkler	Distance from sprinkler (yds.)	Rate of precipitation (mm./hr.)	Minimum temperature (° F.)	Per cent. of flowers killed	Number of ripe fruits picked
Control	—	—	24·1	99·9	0
A. Small rotary (metal) ..	7	0·9	25·6	85·9	2
A. Small rotary (plastic)	7	0·9	—	94·1	0
C. Oscillating spray line	7	1·9	29·4	92·9	2
B. Rotary spray head ..	7	3·8	30·0	19·6	22

* Trees forced in glasshouse.

Damage to the potato plants was estimated in categories, on the basis of the degree of wilting and blackening of the leaves, category 5 representing a completely wilted and killed plant, and category 0 an undamaged one.

From Table VII it can be seen that sprinkling had a protective effect, although these forced potato plants were naturally very susceptible to frost damage.

The variation of damage to potato plants with the rate of precipitation is well illustrated by Fig. 4. On this occasion, 18th April, 1951, sprinkling was carried

PLATE I

Low Temperature Injury to Fruit Blossom.
IV. Further Experiments on Water-Sprinkling as an Anti-Frost Measure.
By W. S. Rogers, Irena Modlibowska, J. P. Ruxton and C. H. W. Slater

Fig. 3.

Ice formed on apple trees by 10 hours' experimental sprinkling during a winter frost (10th-11th December, 1952). Two of the Type A sprinklers used are seen in the foreground and middle distance.

[*face p.* 136.

PLATE II

(*a*)

Distance from sprinkler	50	9	7	6	yards.
Precipitation	Nil	Nil	0·84	2·0	mm./hr.

(*b*)

Distance from sprinkler	50	24	22	20	18	yards.
Precipitation	Nil	Nil	Trace	1·0	5·0	mm. hr.

FIG. 4.

Degrees of protection afforded to potato plants by continuous water sprinkling in a frost of grass minimum 25·0° F. (−3·9° C.).

(*a*) with Type A sprinkler. (*b*) with rotary rainer, Type D.

Table VII.

Minimum temperatures of, and damage to, potato plants (forced).

Sprinkler	Distance from sprinkler (yds.)	Rate of precipitation (mm./hr.)	Minimum temperature (° F.)	Category of damage*
Control	—	—	24·5	5
A. Small rotary (metal)	4	3·5	26·6	4
A. Small rotary (plastic) ..	4	3·6	27·9	4
B. Rotary spray head	4	5·2	28·8	2
B. Rotary spray head	10	1·8	28·4	4
B. Rotary spray head	10	2·9	—	4
C. Oscillating spray line.. ..	4	4·6	26·6	2-3
C. Oscillating spray line.. ..	10	nil	24·1	5

* 0 = no damage. 5 = plants killed.

out on a ley, near Bradbourne gardens, to which forced potato plants in pots were brought. The screen minimum in the gardens was 28·8° F. (−1·4° C.) and the grass minimum was 25·0° F. (−3·9° C.). Two types of sprinkler were used, a Type A sprinkler, and a large rotary rainer (Type D, size R2), covering a circle of about 130 ft. diameter and having an output of about 38 gal. per min. from a ½-in. nozzle at a pressure of about 70 lb. The plants were sprinkled for about 8 hrs. It can be seen that in addition to the protection given to the plants which were sprinkled, those which were just outside the sprinkled areas, where no measurable amount of water was recorded, but down-wind, were less damaged than the controls which were well clear of the sprinkled areas.

The fine mist sprinklers (Type E) were included in eight experiments which will not here be described in detail. In these sprinklers a jet of water impinges on an anvil and is finely broken up. It was found that these sprinklers gave effective water distribution and protection from frost if a sufficiently close array of nozzles was used to ensure a continuous and sufficient precipitation whatever the air drifts ; but the small range of these sprinklers made such a large amount of piping necessary that their use on an orchard scale was considered impracticable.

III. Intermittent sprinkling.

Eight experiments included observations on intermittent sprinkling, which is the term used when water is applied at relatively long intervals. For practical purposes, sprinklers which revolve at a speed of less than about 2 revolutions per minute may be regarded as producing intermittent sprinkling. Such sprinkling produces relatively large temperature fluctuations. Fig. 5, taken from the chart of the Kent recorder, illustrates this point.

In this experiment the rotary spray head was revolving at a rate of one revolution

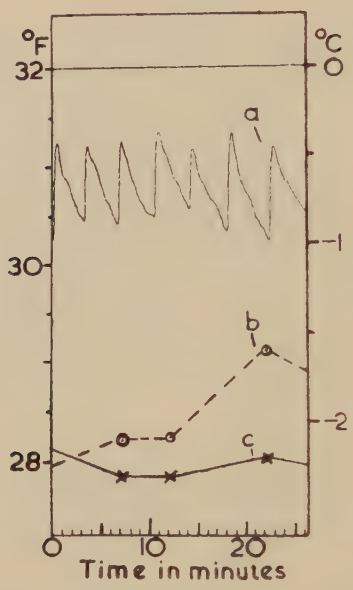

FIG. 5.

Photograph of recorder chart showing (*a*) the temperature of a potato disc sprinkled intermittently, with (*b*) air temperature in control (unsprinkled) area at 4 ft. 6 in., and (*c*) temperature of unsprinkled potato disc, drawn in on the same scale.

every 3 min. 40 sec., and the over-all rate of precipitation was 4·8 mm./hr., approximately 0·27 mm. falling on a given point every time the sprinkler passed over it. The sprinkled object was a disc of potato tissue (1 cm. in diameter and 1 cm. thick), and the temperatures of the air (unsprinkled) at 4 ft. 6 in., as recorded by a thermocouple, and of an unsprinkled potato disc have been added for comparison.

Water falling on the potato disc froze and produced an immediate rise in temperature of from 0·5° to 1·0° F. (0·3° to 0·5° C.). The temperature then fell steadily until, the sprinkler having completed its revolution, water fell again on the potato disc and the process was repeated. The temperature thus fluctuated at known rates between 31·3° and 30·2° F. (—0·4° and —1·0° C.).

Similar records from other experiments show that the faster the speed of rotation the less the fluctuation in temperature, the curve always being of the form of that shown in Fig. 5. Conversely, the slower the speed of rotation the greater the fluctuation in temperature and the greater the risk that during the interval between any two successive sprinklings the temperature of the sprinkled object might fall to a damaging level.

The greater the quantity of water falling on a given object at each revolution, the slower can be the speed of rotation ; but this only applies within limits, for it is obviously undesirable to apply too much water. In fact, the method of sprinkling with water to prevent frost damage operates most efficiently by the more or less continuous freezing of relatively small quantities of water.

The results presented in Table V show that a rotary spray head (Type B), having a speed of rotation of 1 revolution in 48 sec. and a rate of precipitation of

2·9 mm./hr. gives very satisfactory results in a screen frost of 25·5° F. (−3·6° C.). This result compares favourably with those obtained from the Type A unit which, rotating at about 80 to 120 r.p.m., provides practically continuous sprinkling. Other factors associated with the two types of sprinkling have already been discussed.

DISCUSSION.

These experiments have shown clearly the relationship between precipitation rate and temperature rise under given conditions.

In theory the most economical use of sprinkling is obtained when (*a*) the size of the drop is such that it does not run off before freezing, and (*b*) the interval between successive drops is such that one drop freezes before the next falls. Thus the optimum frequency of drops of a given size increases with decrease in temperature. Excessive application of water, apart from being wasteful and possibly harming the soil, is in fact less effective, for it hampers ice formation. A warming effect (1 cal./gm./° C.) is indeed gained as the water cools to the freezing point, but the greatest warming effect is gained from the liberation of the latent heat of freezing (80 cal./gm.). Some run-off from the leaves is almost inevitable, but water freezing on the ground also adds its quota of heat and helps to raise the air temperature.

It is difficult to arrange for a graduated increase of precipitation as the temperature falls, for changes in the water pressure affect not only output, but also droplet size and spread. Thus, in practice, it is simplest to choose the precipitation rate that is optimum for the minimum temperature against which it is intended to guard, and arrange the sprinklers accordingly.

Taking a number of experiments into consideration, and bearing in mind that since these investigations were started there have been no spring frosts at blossom time in which to apply the crucial test, the values of the rate of precipitation expected to provide protection to apple blossom in different degrees of frost are as given in Table VIII. These values assume that 28° F. (−2·2° C.) is the critical temperature for frost damage to apple blossom (unsprinkled) and that the bud temperature (see above) is about 1·5° F. (0·8° C.) lower than the screen temperature.

It is stressed that the results given in Table VIII represent a mean value and can only be expected to operate under radiation conditions, when air movement is about 2·0 m.p.h. or less.

In this series of experiments no wind frosts severe enough to allow critical data to be collected, were encountered; but preliminary experiments suggest that, with stronger winds, higher precipitation rates would be needed for a given degree of protection. Further work on this aspect is necessary.

Table VIII.

Protection expected from different rates of precipitation, for apples in full bloom, under radiation frost conditions.

Rate of precipitation (mm./hr.)		2	4	6
Protection given in screen minimum of	° F.	26·0	23·5	21·5
	° C.	−3·3	−4·8	−5·8

The figures refer to a sprinkled area of ¼ acre and a wind speed of 2 m.p.h.

In both radiation and wind frosts, increasing the area sprinkled would be expected to increase the efficiency of the process.

The temperature at which it is desirable to start sprinkling depends on several factors. Among these are the temperature at which critical damage occurs to the plants, the extent to which supercooling takes place, and the freezing point of the cell sap. These factors may vary from species to species and from variety to variety. They will also vary with the weather conditions before the frost, the physiological state of the plant, and the stage of development of the plant. Generally speaking, however, for apple blossom, where the critical temperature for damage is commonly about 28° F. (−2·2° C.), if sprinkling were started when the temperature of the air had fallen to 29° F. (−1·7° C.) a high degree of protection would still be obtained. An important practical point, however, is that if relatively small nozzles were used they might become blocked with ice spicules formed in the pipes, if sprinkling were delayed until 29° F. (−1·7° C.) is reached. For safety, in such cases, the water should be turned on shortly after an air temperature of 32° F. (0° C.) is reached. With larger nozzles, as used, for instance, with rotary rainers, it is provisionally suggested that the starting of sprinkling may be delayed until the air temperature reaches about 30° F. (−1·2° C.).

At the end of a frost, it appears safe to stop sprinkling if the plants are at a temperature above that at which damage occurs to them, if the air temperature is rising rapidly, and if the sun has risen above the horizon. For apples the temperature (of the air) at which sprinkling may be stopped at the end of a radiation frost is probably about 30° F. (−1·2° C.). Under wind frost conditions it would probably be desirable to wait until the temperature of the air had reached 32° F. (0° C.), before sprinkling was stopped.

The practical applications of the method of sprinkling plants with water to prevent frost damage have been discussed by Rogers (1952, 1953).

SUMMARY.

1. Laboratory and field experiments on sprinkling plants with water as an anti-frost measure are described.

2. The more severe the frost the greater the amount of water required to maintain a given temperature. In radiation frosts with a wind speed of 2 m.p.h. or less, a precipitation rate of 2 mm./hr. is likely to protect apple blossom from a screen minimum of 26° F. (−3·3° C.); 4 mm./hr., from 23·5° F. (−4·8° C.); and 6 mm./hr. from 21·5° F. (−5·8° C.). If the wind speed is higher, the protective effect is correspondingly reduced.

3. The start of sprinkling may be delayed until shortly after the temperature of the air has fallen below 32° F. (0° C.).

4. Sprinkling may safely be stopped when the air temperature has returned to 32° F. (0° C.), and if there is no wind and the temperature is rising rapidly, it is probably safe to stop sprinkling when the air temperature has risen to 30° F. (−1·2° C.).

5. The ice formed by sprinkling caused the branches of mature apple trees to bend, but did not break them.

6. The results are discussed with special reference to protecting apple blossom in the spring.

7. The field tests included rapidly rotating small sprinklers, impact sprinklers, oscillating spray lines, a large rotary rainer, and fine mist sprinklers.

ACKNOWLEDGMENTS.

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STUDIES ON THE MATURITY OF APPLES.

RESPIRATION PROGRESS CURVES FOR COX'S ORANGE PIPPIN APPLES FOR A NUMBER OF CONSECUTIVE SEASONS

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THE present work was initiated to follow the changes in respiratory activity from season to season in fruit of one variety from the same trees in a well-managed commercial orchard. The respiration rate was measured at two temperatures over a period a week or two before and extending to a week or two after the normal picking date, with a view to the establishment of some focal point in the time pattern of respiration activity which would serve as an index of physiological maturity. If this focal point could be *forecast* by, for example, extrapolation sufficiently early in each growing period it would serve as a guide to a commercial picking date that would be uniform as regards maturity, irrespective of season. This would greatly simplify comparative trials of the storage behaviour of fruit in different seasons. It should, in fact, eliminate the " maturity factor " in such trials. The onset of the respiration climacteric itself is of little value in this connection, since it occurs too late to serve as a guide to picking for long storage life.

EXPERIMENTAL

With one exception (East Malling, 1951) all the fruit used came from 10 Cox's Orange Pippin trees (10 years old in 1946) on a cultivated and strawed-down orchard at Ardleigh, in Essex. At each picking date, fruit was picked at random from the trees and transported to Ditton Laboratory on the same day. Samples were immediately prepared, each sample being made up of 25-30 fruits including approximately the same number of apples from each tree. The samples were then placed in desiccators in a train of apparatus designed to measure the CO_2-production of the fruit by absorption in sodium hydroxide solution (Hulme, 1937). These respiration-trains were situated in a room, the temperature of which was kept constant ($\pm 0{\cdot}5°$ C.) at 12 or 15° C. as required. Since even samples containing as many as 25-30 fruits may show a difference of at least one day in the onset of the respiration climacteric (R.C.) when picked near the time of onset of this climacteric on the tree, duplicate samples were used at each pick and the results plotted in the graphs are the mean values obtained. When the fruit is in a " critical " state on picking (i.e. about to develop a R.C.) the times of onset of the rise may occasionally differ by several days in the duplicate samples, although the duration of the rise is the same; with the result that the mean curve shows a rise more prolonged than that shown by either of the two samples, and is hence a " distorted " curve. In the Figures the mean curve has been taken as representing the average respiration state of like

samples on the dates plotted, but in Table I the duration of the rise is the mean of the separate durations for the two samples. In the majority of samples, agreement between duplicate samples was very close. This will be seen from the length of the vertical lines drawn at the side of the letters identifying the separate progress curves in Figures 1 and 2 ; these lines represent the divergence between duplicate samples *at the R.C. peak.*

The dates of petal fall in each season were as follows : Ardleigh : 1947, 18th May ; 1948, 14th May ; 1949, 19th May ; 1950, 21st May ; 1951, 28th May ; 1952, 12th May. East Malling : 1951, 28th May.

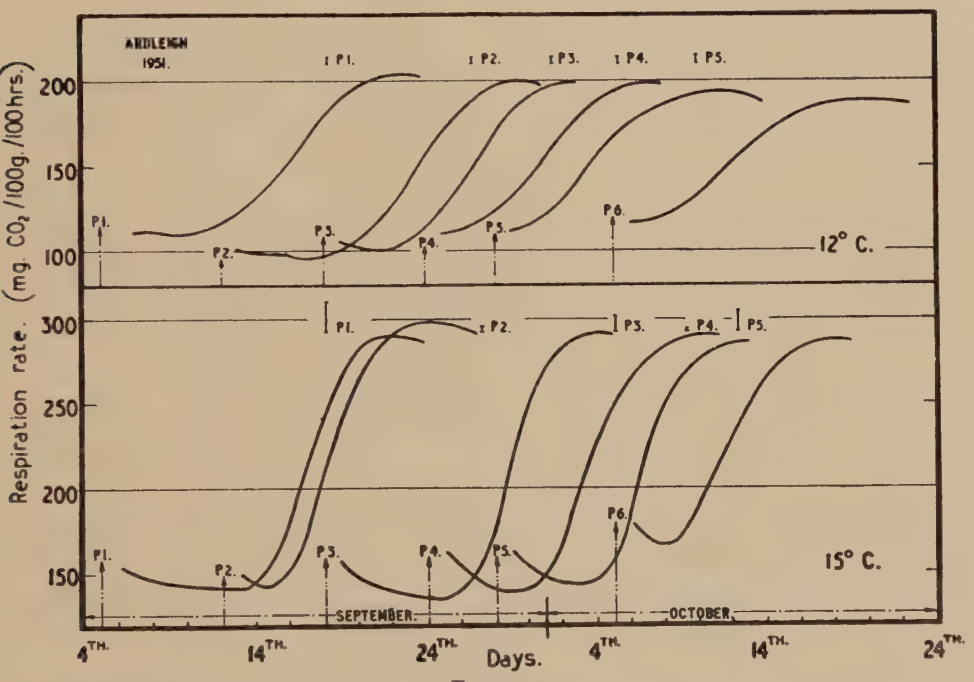

FIG. 1.

Respiration rate at 12° C. and 15° C. of Cox's Orange Pippin apples from Ardleigh in 1951. (For explanation see text.)

RESULTS

Examples of the sets of progress curves obtained in different seasons are given in Figures 1-3, the results for 12° C. being shown above those for 15° C. The date of each pick is indicated by the vertical lines with an arrow head, along the time axis ; the pick number is indicated by " P " followed by a figure above the arrow heads. Similar sets of data were obtained for the Ardleigh fruit for the years 1947, 1948, 1949 and 1950. These will not be presented in full here, but relevant derived data are given in Table I, which also shows the dates at which the various pickings were made in each season.

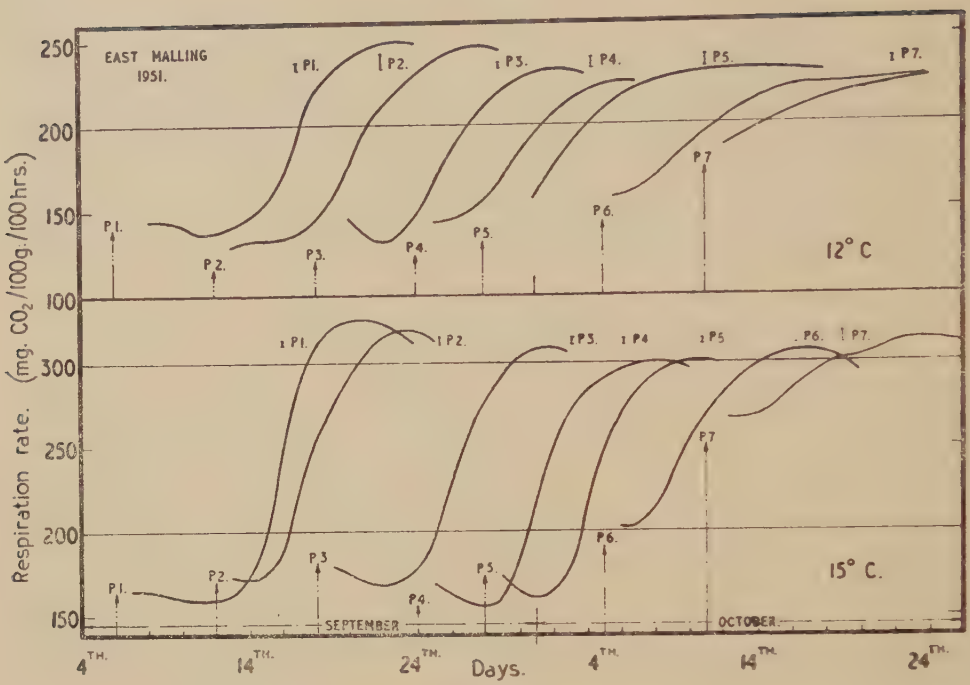

FIG. 2.

Respiration rate at 12° C. and 15° C. of Cox's Orange Pippin apples from East Malling in 1951.

The minimum respiration-rate immediately prior to the climacteric rise, the respiration rate at the climacteric peak and the extent and duration of the rise are given in Table I for both 12° and 15° C.

The times taken from the commencement of the climacteric to the peak are the means of the separate durations for the duplicate samples.

Certain peculiarities in the behaviour of the fruit in 1952 must be mentioned. Before the onset of the climacteric, both at 12° C. and 15° C., but not at exactly the same time, a minor peak in the respiration rate occurred (Fig. 3) in the fruit of picks 1 and 2 at 12° C. and picks 1, 2 and 3 at 15° C. It was at first thought that this " minor climacteric " might have been caused by an escape of ethylene into the air in the neighbourhood of the constant temperature rooms containing the respiring fruit. Investigation showed this to be unlikely. Later it was noticed that all the fruit at 15° C. and some of the later picks at 12° C. developed a disorder known as " lenticel spotting ". Careful examination of the fruit suggested that the lenticels suffered some form of physiological breakdown in the first instance which was later followed by fungal attack. The date at which lenticel damage first became visible in the 1952 fruit is indicated in Fig. 3 by an arrow surmounted by " L.S.". It is possible that there is some connection between the pre-climacteric hump in the respiration curves for the early picks and the lenticel damage. Neither phenomena were present in the fruit of other seasons. When fungal attack in the region of the

TABLE I.

The respiration rate of Cox's Orange Pippin apples during the climacteric rise.

Source of apples	Date of picking	Pick No.	Respiration rate over climacteric rise (mg. CO_2/100 g./100 hrs.)						Date† of climacteric peak		Mean time between min. and max. (days)	
			12° C.			15° C.						
			Min.*	Max.	Rise	Min.*	Max.	Rise	12° C.	15° C.	12° C.	15° C.
Ardleigh, 1947	28th Aug.	1	108	194	86	126	274	148	20th Sept.	15th Sept.	12	11·5
	5th Sept.	2	106	194	88	126	275	149	24th Sept.	20th Sept.	11	10
	11th Sept.	3	—	—	—	122	264	142	—	26th Sept.	—	9
	16th Sept.	4	106	192	86	120	259	139	2nd Oct.	1st Oct.	11	10
Ardleigh, 1948	31st Aug.	1	128	248	120	160	320	160	19th Sept.	15th Sept.	12	11
	8th Sept.	2	130	244	114	158	322	164	25th-27th Sept.	23rd-24th Sept.	12	12
	13th Sept.	3	133	235	102	162	316	154	29th-30th Sept.	27th Sept.	12	9
	16th Sept.	4	127	226	99	154	308	154	2nd-4th Oct.	30th Sept.	12	11
Ardleigh, 1949	31st Aug.	1	122	220	98	136	282	146	23rd Sept.	19th Sept.	13	12
	6th Sept.	2	112	218	106	136	272	136	24th-25th Sept.	22nd-23rd Sept.	14·5	12·5
	12th Sept.	3	112	214	102	134	278	144	29th Sept.	27th-28th Sept.	11	11·5
	15th Sept.	4	114	213	99	130	280	150	3rd-5th Oct.	29th Sept.	12	13
Ardleigh, 1950	28th Aug.	1	135	265	130	175	342	167	18th-19th Sept.	11th-12th Sept.	13	11
	4th Sept.	2	128	264	136	166	336	170	23rd-24th Sept.	18th Sept.	14	13
	9th Sept.	3	135	264	129	154	330	176	26th-27th Sept.	26th Sept.	11	10·5
	18th Sept.	4	136	254	118	174	331	157	4th Oct.	3rd Oct.	12	11
	22nd Sept.	5	(166)	258	(92)	(215)	344	129	7th Oct.	4th Oct.	10	9
Ardleigh, 1951	5th Sept.	1	129	224	95	144	291	147	21st-22nd Sept.	20th Sept.	12	10
	12th Sept.	2	116	220	104	144	298	154	29th Sept.	24th Sept.	11·5	9
	18th Sept.	3	119	220	101	136	292	156	3rd Oct.	4th Oct.	11·5	9
	24th Sept.	4	130	219	89	139	290	151	6th-7th Oct.	9th-10th Oct.	11·5	9·5
	28th Sept.	5	133	214	81	144	286	142	11th Oct.	13th Oct.	10·5	9
	5th Oct.	6	(136)	209	73	(166)	286	120	19th Oct.	18th-19th Oct.	12	10
East Malling, 1951	6th Sept.	1	135	248	113	159	325	166	22nd Sept.	20th Sept.	11	8
	12th Sept.	2	132	246	114	172	320	148	27th Sept.	23rd-24th Sept.	11·5	8·5
	18th Sept.	3	130	230	100	167	308	141	1st Oct.	30th Sept.	10	8·5
	24th Sept.	4	(142)	226	84	156	302	146	4th-5th Oct.	7th Oct.	10	10
	28th Sept.	5	(156)	230	74	161	301	140	11th-12th Oct.	11th Oct.	9	8·5
	5th Oct.	6	(158)	225	67	(202)	306	104	17th Oct.	15th Oct.	11	10
Ardleigh, 1952	25th Aug.	1	138	253	115	166	339	173	16th-18th Sept.	13th-14th Sept.	11	11
	29th Aug.	2	134	254	120	149	339	190	20th-21st Sept.	19th Sept.	13	11·5
	3rd Sept.	3	126	248	122	156	332	176	26th Sept.	24th-25th Sept.	13	12
	9th Sept.	4	141	263	122	164	334	170	27th-29th Sept.	29th Sept.	13	12
	12th Sept.	5	150	264	114	170	346	176	28th-30th Sept.	29th-30th Sept.	14	11
	17th Sept.	6	142	258	116	212	334	122	4th Oct.	29th-30th Sept.	13·5	9
	22nd Sept.	7	(188)	282	94	218	345	127	5th-6th Oct.	3rd-4th Oct.	10	8
	26th Sept.	8	(180)	267	87	(230)	338	108	8th-9th Oct.	7th Oct.	9·5	9
	1st Oct.	9	(218)	272	54	(279)	(380)	101	11th-12th Oct.	11th Oct.	8	8

* Figures in brackets indicate that the climacteric on the tree was well advanced when the fruit was picked.

† By inspection of the mean curves of respiration rate the actual peak may be seen to occur half way through a day. This "exact" time has been taken in constructing the curves in Fig. 5.

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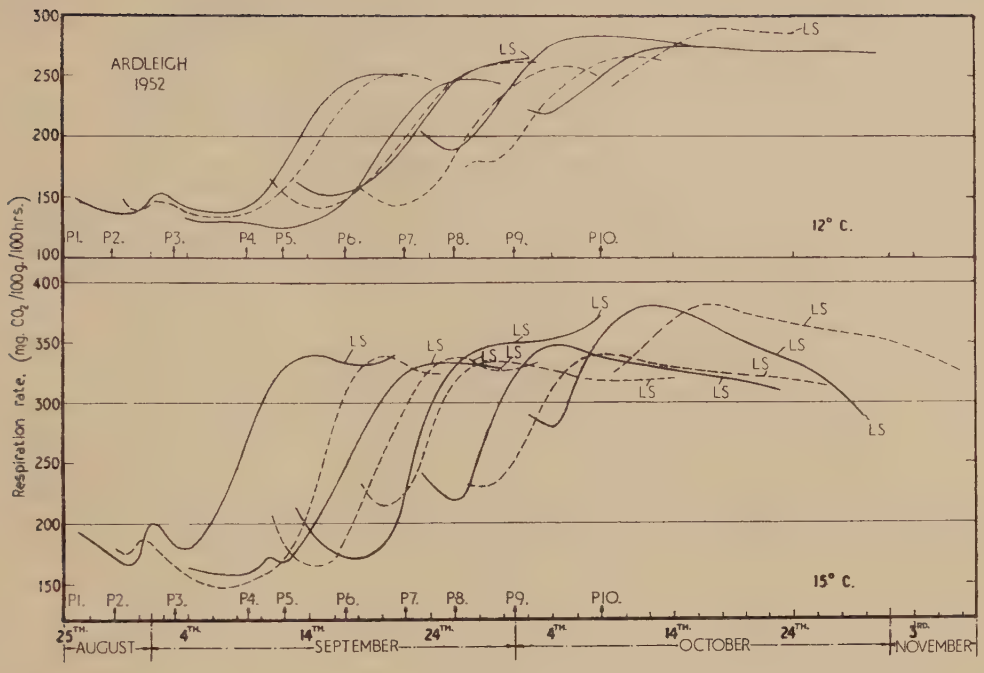

FIG. 3.

Respiration rate at 12° C. and 15° C. of Cox's Orange Pippin apples in 1952. (For explanation see text.)

lenticels became serious an increase in the respiration rate of the " fruit " occurred, due (probably) to the high respiration rate of the attacking fungi. The point at which the fungal attack became appreciable was, in some picks, near the climacteric peak. In these samples it was necessary to exercise care in locating the date of the peak because the rising rate of respiration associated with the development of lenticel-spot tended to obscure the post-climacteric fall in respiration rate. This factor, serious only in the fruit at 15° C., has been taken into account in drawing up the data in Table I. The pre-climacteric hump has been discounted in assessing the point at which the climacteric rise commenced.

DISCUSSION.

In considering the variation from season to season in physiological maturity and the relative values of the rates of respiration of the picked fruit at the two temperatures, note must be taken of the dates of petal fall. In 1948 and 1952 petal fall was early, in 1951 it was noticeably late. While a big difference, such as between 12th-14th May (1948, 1952) and 28th May (1951) may still affect maturity in September, the growing season for Cox's Orange Pippin apples occupies more than three months, and during this length of time there is a general " levelling effect ". The temperature and rainfall have probably more effect on the maturity of the fruit at the end of the growing period (September) than the date of petal fall when this

only differs by a few days. It is not likely, therefore, that differences in maturity and respiration rate at picking in 1947, 1949 and 1950 will be due to differences in date of petal fall. Maturity will be referred to again later.

The salient facts which emerge from a survey of the respiration data as summarized in Table I are :

(i) The respiration rates of the Ardleigh fruit, both at the minimum before the commencement of the climacteric rise and at the climacteric peak, are in successive years alternately high and low. This applies at both temperatures. The extent of the rise during the climacteric also alternates, being low in 1947, high in 1948, and so on. These facts are best brought out by the curves in Fig. 4, which are drawn to represent the average climacteric rise in each season, omitting picks where the climacteric rise had already commenced on the tree. Although Cox's Orange Pippin is not a biennial bearing apple, this alternation in respiratory levels may be somewhat akin to the phenomenon of biennial bearing. It seems unlikely that it is due to regular alternation over such a span of years in climatic conditions during the growing period. On the assumption that the East Malling fruit does not have consistently higher respiration rates than the Ardleigh fruit, an assumption supported by other data for 1952, not included here, the high rates shown in Table I for the East Malling apples in 1951, a low year for the Ardleigh fruit, suggest that these two crops may be out of step.

There is, at present, no evidence of any effect of this regular fluctuation in the level of respiration on storage life or on the incidence of storage disorders. If a commonly held view (Smith and Hulme, 1953) that a low

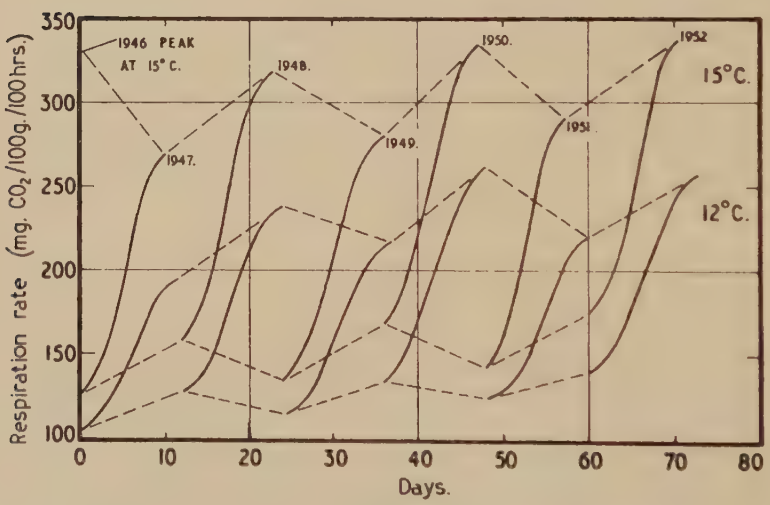

FIG. 4.
Fluctuations in the "average" climacteric rise in rate of respiration at 15° C. and 12° C. of Cox's Orange Pippin apples over several consecutive seasons.

rate of respiration favours long storage life is generally valid, there should be some indications of a regular biennial variation in storage life, or in susceptibility to disorders such as low temperature breakdown or carbon dioxide injury, which under certain conditions may reduce storage life. No such regular biennial fluctuations have, however, been reported as yet.

(ii) Up to the point when the climacteric has already commenced on the tree, the time interval between the onset and the peak of the climacteric rise is surprisingly constant (Table I). At 12° C. the time taken was 12-14 days ; at 15° C. the time was about one day less.

(iii) The point at which the climacteric commences on the tree can be estimated from the data for seasons in which later picks were made. In no case does it occur before about 18th September. There is evidence of its commencement in 1950 and 1951 (rather earlier in the East Malling than in the Ardleigh fruit), while its progress may be clearly seen from the fuller series of respiration curves obtained for 1952 (Fig. 3).

(iv) A survey of the times of the climacteric onset and peak of apples stored at 12° C. and 15° C. respectively reveals a relation to date of picking and to season that may be of some importance. For any pick the time interval or " gap " between the attainment of the climacteric at 15° C. and its attainment at 12° C. is not constant, but appears to vary in a regular manner with date of picking. Since from the respiration curves the point in time of the peak is more easily defined than the point in time of the onset, the dates of the peaks will be used : these dates are given for each temperature in Table I and the data derived from them are shown graphically in Figure 5. In this figure the ordinates represent the number of days (z) between the attainment of the climacteric peak at 15° C. and at 12° C. Where the peak occurs at 15° C. before the peak at 12° C., the values of z are positive, and where the peak occurs at 12° C. first—and, rather surprisingly, this does occur—the values are negative. The abscissae represent dates and the actual points on the graphs each correspond with the date of picking of the particular samples.

Apart from 1947, for which respiration data both at 12° C. and 15° C. are available only for 3 of the 4 picks, the points fall on curves showing a pronounced and fairly sharp minimum. The inflection indicated for 1947 is conjectural only since it is impossible to decide whether the true minimum value falls before or after pick 4 (16th September). In 1952 there is some scatter in the last three points which may be due to the " abnormal " condition of the fruit mentioned earlier. 1952 was the " earliest " season (petal fall, 12th May) and after pick 6 (17th September) the respiration data show that the climacteric was in progress on the tree ; a falling off in the " gap " between the dating of the peaks at the two temperatures for the picked fruit might be expected under these conditions.

The close agreement in the " date of minimal gap " between the fruit from Ardleigh and that from East Malling in 1951 is striking, especially in view of the consistent difference in the level of respiration of the two sets of fruit (Table I).

In general, then, the progress of the time gap between the climacteric peaks at 15° C. and at 12° C. shows a consistent pattern throughout all

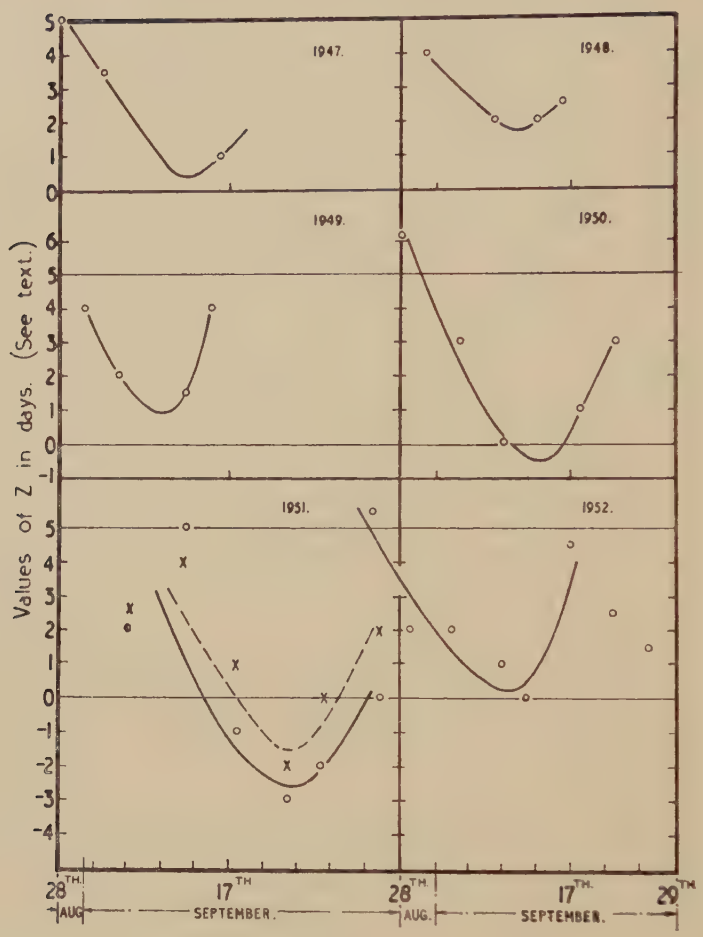

FIG. 5.

Changes in the gap between the climacteric peak at 15° C. and 12° C. in consecutive picks of Cox's Orange Pippin apples for the seasons 1947 to 1952.
o — o : Ardleigh fruit. x — x : East Malling fruit.

the seasons, and it seems possible that the date at which the gap is minimal reflects a definite physiological state of the fruit. This point occurs earliest in the season with the earliest date of petal fall (1952), i.e. at about 10th September, and latest in the season with the latest date of petal fall (1951), i.e. at 24th September.* It remains for future work to decide whether this " point of minimal gap " is of value as a criterion of " absolute " maturity in relation to picking for maximum storage life.

* It should be noted that 1952 and 1951 were also early and late respectively from the point of view of onset of climacteric on the tree.

From a physiological viewpoint, interest lies firstly in the fact that at a certain stage in the development of the fruit the climacteric in picked fruit may occur sooner at 12° C. than at 15° C. (1950 and 1951), and secondly that later picked (but still probably preclimacteric) fruit shows a return to the condition in which, when the fruit is picked, the climacteric occurs sooner at 15° C. than at 12° C. This again opens up the question of the nature of the change within the fruit which is manifest in the onset of the respiration climacteric. It has been suggested (Hulme, 1954) that the net increase in protein-content which occurs in the region of the climacteric represents an increase in, or a change in the balance of, the enzymes present in the fruit. If there is a change in function of the fractions of the " total enzymes ", then the new enzyme systems might have different temperature coefficients.

SUMMARY.

1. Data are presented for the respiration rate of Cox's Orange Pippin apples picked over a period extending from a few weeks before to a few weeks after the " commercial " picking dates and kept at 12° C. and 15° C. The rates of respiration were measured over a number of seasons.

2. The significance of differences in the level of respiration and of the height of the respiration climacteric from season to season is discussed, and it is shown that there is a regular biennial variation in the level of respiration.

3. The difference in time between the onset of the respiration climacteric at 12° C. and at 15° C. is shown to vary with the date of picking, and this " time-gap " has a minimal value which may vary from season to season. It is suggested that this " point of minimal gap " reflects a definite physiological state of the fruit which may prove to be a guide to " absolute " maturity in relation to picking for maximum storage life.

4. The physiological significance of the results presented is discussed.

ACKNOWLEDGMENTS.

Messrs. King and Wooltorton carried out much of the practical work involved.

The work described in this paper was carried out as part of the programme of the Food Investigation Organization of the Department of Scientific and Industrial Research, and is published by permission of the Director.

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STOCK AND SCION INVESTIGATIONS

X. INFLUENCE OF AN INTERMEDIATE STEM-PIECE UPON THE SCION IN APPLE TREES

By L. A. THOMAS
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THE modern apple orchard is one in which there are trees of a few varieties which are in commercial demand, and many trees of obsolete varieties have been "worked over" to these favoured kinds. The original variety then forms an intermediate stem or a system of stems between the rootstock and the top scion.

The question arises whether the top scion is invigorated or dwarfed in its growth by this intermediate stem-piece. Roberts (1929) compared the growth of a number of apple varieties as single-worked and double-worked trees, but only Jonathan on a range of intermediate stem-pieces grew larger than Jonathan as a single-worked tree. Barker (1928) states that rootstocks produce little or no real increase in the growth vigour of any scion. There is, on the other hand, evidence showing reduced growth in the top scion due to a 2-in. intermediate stem-piece. Tukey and Brase (1933) give measurements and illustrations showing the small growth of Winesap scions with Northern Spy and Titovka as intermediate stems. Hatton (1930) reports that, in experiments carried out by Grubb at East Malling, whilst a 3-in. length of an intermediate stem produced an effect, 2 ft. of the same intermediate intensified it.

If, therefore, in the reworking of one variety to another, the major part of the trunk and branches of the original scion remains, it is to be expected that the influence of this intermediate stem will be nearly at its maximum. To determine whether this influence is important to horticulturists, several obsolete varieties were chosen as intermediate stems, and two commercial apples, Jonathan and Delicious, used as top scions.

MATERIAL AND METHODS.

Two sets of trees were propagated on Malling II rootstocks ; one set was stem-budded in 1938 to Rymer, Nickajack, Scarlet Pearmain, Duke of Clarence and Jonathan and, in 1939, at a height of 15 in. above this union, budded to Jonathan. The second set of rootstocks was budded in 1937 to Dunn's Favourite, Emperor Alexander, Scarlet Pearmain, Duke of Clarence, Nickajack, Reinette du Canada and Delicious, and similarly double-worked to Delicious in 1939.

It is emphasized that both Jonathan and Delicious trees on M.II were each budded to their own scion variety to produce trees budded at two points for comparison with the double-worked trees. However, such trees cannot with accuracy be described as single-worked trees. Both series of trees were planted out at 5 ft. × 4 ft. as randomized trials. In the Jonathan trial there were seven replications of four-tree plots of each combination ; in the Delicious trial there were always

five replications, but the number of trees per plot varied, there being five for Reinette du Canada, Delicious and Emperor Alexander, four for Scarlet Pearmain, Duke of Clarence, and three for Nickajack and Dunn's Favourite. The trees were trained to a single leader and given an annual light winter pruning.

Records for the Jonathan trees included the girth of the intermediate stem-piece measured 3 in. below the union with the Jonathan scion and girth of the Jonathan top scion at 3 in. above the union. The trees were dug in June, 1946, and the Jonathan scions weighed. Records for the Delicious trees included the annual shoot growth from 1939 until 1945, girth of the intermediate stems at a fixed point, crops borne and weight of the Delicious top scion in 1948.

RESULTS.

Jonathan. The data for growth and cropping are presented in Table I.

TABLE I.

Mean size and cropping of Jonathan apple double-worked on M.II with various intermediates.

Intermediate stem-piece	Weight of scion (oz.). 1946	Girth (cm.). Jonathan top scion	Girth (cm.). Intermediate stem-piece	Yield per tree (lb.)
Jonathan	91·8	13·9	14·4	24·9
Rymer	80·4	12·8	15·1	28·2
Nickajack	67·8	12·3	13·5	18·2
Scarlet Pearmain ..	57·0	10·9	12·8	17·4
Duke of Clarence ..	51·0	10·3	10·7	20·3
Minimum difference for significance P = 0·05	25·1	0·95	0·97	3·6

TABLE II.

Mean size and cropping of Delicious apple double-worked on M.II with various intermediates.

Intermediate stem-piece	Weight of scion (lb.). 1948	Accumulated growth (m.). 1939-1945	Girth of intermediate (cm.). 1948	Crop per tree (lb.). 1941-1948
Delicious	13·1	117·9	19·5	66·3
Nickajack	10·2	80·8	20·7	49·0
Scarlet Pearmain	9·3	100·9	20·9	64·0
Duke of Clarence	9·2	73·9	17·4	65·1
Dunn's Favourite	7·9	80·7	18·2	61·2
Emperor Alexander	7·8	78·3	16·9	57·4
Reinette du Canada ..	7·8	77·4	19·1	54·5
Minimum difference for significance P = 0·05 ..	3·22	20·0	1·72	13·5

Table I shows that in no instance have trees with foreign intermediate stem-pieces made greater growth than Jonathan trees double-worked on themselves.

The trees with Rymer intermediates and those with Jonathan double-worked on itself matured heavier crops than all other combinations.

Delicious. Table II shows that, as with Jonathan, none of the trees with an intermediate stem of another variety have grown larger or borne heavier crops than Delicious trees double-worked on themselves on Malling II stocks.

DISCUSSION.

As it appears from this study that the re-working of trees to other varieties may result in a stunting of the top scion to some degree, and the lessening of fruit production, closer attention needs to be given to the combination of scions used in re-working. A survey of orchard trees already re-worked should yield valuable information.

SUMMARY.

The introduction of an intermediate stem-piece of several apple varieties between the rootstock Malling II and the ultimate scion, Jonathan or Delicious, has generally resulted in decreased vegetative growth when compared with Jonathan and Delicious double-worked on themselves on Malling II stocks. In no instance have the trees with intermediate stem-pieces grown larger or out-yielded the trees with the simpler make-up.

ACKNOWLEDGMENT.

My thanks are due to Mr. G. A. McIntyre who carried out the statistical analyses of the results.

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REVIEWS

SCIENCE AND FRUIT. Ed. by T. WALLACE and R. W. MARSH. (University of Bristol. 1953. Pp. xiii+308, illus. Price 30s.)

Fifty years ago was founded at Long Ashton the National Fruit and Cider Institute, which later developed into the Long Ashton Research Station, a permanent memorial to the vision of its initiator, Neville Grenville. The present volume commemorates the activities of the past half century, for two years under the guidance of a non-resident Director, Mr. Lloyd, then for thirty-eight years under Professor Barker, and for the last decade under the present Director, Professor Wallace.

These pages comprise some twenty-six contributions, mostly presenting various aspects of the investigations that have been carried on at Long Ashton, as well as others of a more general character, such as the brief foreword by Sir Winston Churchill, and the "Jubilee Address" by Lord Rothschild. To many of the numerous friends of the Station, not the least interesting of these will be the account of its history and development during the formative years. There are the strengthening links with the University, a growing integration of fundamental and applied aspects on the one hand, yet a maintenance of the close association with industry on the other. The extension from an area of only 13½ acres at its inception, to the 257 acres acquired in 1920, is but one indication of the continuous growth, paralleled by the growth of the laboratories and above all by that of the scientific staff.

The research aspects are grouped for convenience under five headings, namely, Fruit Culture, Nutrition, Pathology, Cider and Fruit Juices, and Food Preservation, but despite this segregation, the underlying unity of these different facets of the problems connected with fruit and vegetable production is nevertheless manifest.

Although the research at Long Ashton has by no means been confined to the apple and its products, that is the chief common factor of the subjects here dealt with. Thus D. A. Osmond treats of the evidence from soil surveys that both physical and chemical characteristics play an important role in determining the suitability of soil types for fruit growth, whilst Professor Wallace discusses the influence of orchard factors on the quality and storage properties of apples. The complexity of this problem is illustrated by the influence of bark-ringing, which may be conducive to the development of certain defects in storage, whilst tending to reduce the incidence of others. The higher percentages of nitrogen and sucrose in apples from very young trees, as compared with slightly older ones, is indicative of the grosser changes with age, though the more subtle ones that determine the superior eating quality of fruit, especially of some varieties from really old trees, remain to be explored. The influence of grass culture in ameliorating iron deficiency and raising the level of potassium and phosphorus whilst lowering the nitrogen content, provides the fruit farmer with one useful method of nutritional adjustment which appears to have a beneficial effect on storage properties exclusive of variety. A. A. Williams deals with the prospect of utilizing chromatographic methods to distinguish the relative amounts of free amino acids, the pattern of which appears to be a concomitant of environmental changes, and this approach to the study of the phenolic substances likewise appears promising.

The use of sand-culture methods is dealt with by E. J. Hewitt and D. J. D. Nicholas considers the mineral nutrition of *Aspergillus niger* and *Penicillium glaucum* from the point of view of their value in the bio-assay of trace elements such as molybdenum and copper.

T. Swarbrick and L. C. Luckwill contribute a consideration of the factors governing fruit bud formation in which they rightly stress the need for more insight into the physiological processes concerned. The second of these authors describes the work at Long Ashton on growth hormones, which has indicated that in the apple there is present an inhibitor and no less than four growth hormones ; one of the latter originates from the endosperm, and its absence appears to be associated with fruit drop.

Various authors write of pests and diseases, and amongst the six essays in this field the surveys of the past half century of progress with respect to insecticides and fungicides by J. T. Martin, and of the technique of fruit spraying by H. G. H. Kearns and N. G. Morgan, constitute accounts that many will find of interest. In the latter context the low volume high pressure " aerosol " methods developed at Long Ashton are of especial promise.

Finally, though actually placed first in this volume, are five contributions concerning cider and fruit products. Anyone interested in cider for its own sake, or even only from its analogies with the wine industry, will find here a fascinating account of the multifarious factors that combine to produce the final beverage and of the disorders to which it is subject.

Professor Barker appropriately surveys the past history of cider production and assesses the merits of various cider-apple varieties, whilst Dr. Pollard considers the factors affecting quality and envisages the possibility of vintage ciders of special character, vintages such as are well known in wines.

Taken as a whole this commemorative volume embraces a wide variety of topics that serve to emphasize not merely how much has been learnt, but also the rapidly expanding universe of our apprehension of what is unknown, and hence the value of that restrictive integration which a practical aim can effectively provide.

E.J.S.

STATISTICAL SCIENCE IN AGRICULTURE. By D. J. Finney. (Edinburgh : Oliver and Boyd. 1953. Pp. 179, illus. Price 25s.)

Anyone who remembers studying agricultural experimentation even ten years ago knows the proliferation of books and pamphlets that purported to teach their readers statistics, the emphasis being almost entirely on techniques for the handling of data rather than on the principles of sound experimentation. If these publications have fallen into deserved neglect, the reason unhappily does not always lie in a more enlightened attitude to experimentation but in the fact that the student nowadays commonly acquires the same information from lectures. Too often he has had no opportunity to consider how new knowledge is obtained. He may be well informed but only rarely is he equipped to conduct research.

This book is to be warmly welcomed because it does set out very competently the principles that underlie good experimentation. The standing of its author is sufficient guarantee of its soundness, but more than that it is written pleasantly, lucidly and sensibly, with examples admirably chosen to appeal to agricultural

readers. The reviewer was particularly delighted with the apposite quotations that adorn the chapter headings and do so much to start the reader off on a useful line of thought without dogmatizing at him in the text.

The author does not attempt to teach his readers how techniques are derived and, indeed, some will dislike being told so often that such and such a result is the outcome of mathematical investigation with no further explanation, but the non-mathematician must be prepared in his study of statistics to accept much on trust. Also, the author is less concerned to teach the details of statistical techniques than to explain their potentialities so that his reader will know when to seek the services of a statistician. Again, some may be irritated, but this refusal to delve into too much detail is equally wise. The most useful statistical knowledge for an experimenter is a just appreciation of what statistics can do and of what he himself does not know. Even if no statistician is available, this book still has a place, deserving to be read before other works that profess to do more.

This being a review for the *Journal of Horticultural Science*, it is unfortunately necessary to comment that on the two occasions (pages 83 and 125) on which the author leaves agriculture for horticulture, his remarks are likely to mislead. None the less this is a very good book, well conceived, well written and well printed (rather surprisingly so, when it is realized that though written in English it was printed in Denmark), and the author has performed a valuable service in producing it.

S.C.P.

PUBLICATION RECEIVED

ERNTE, SORTIERUNG UND VERPACKUNG VON KERN-, STEIN- UND BEERENOBST. (Harvesting, grading and packing of pome, stone and small fruit.) By F. Hilkenbäumer. (Zweckmässige Arbeitsweise im Obstbau. 1953. Heft 8/9, pp. 111, illus.)

ROYAL HORTICULTURAL SOCIETY

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1. The **Journal of Horticultural Science** is an official organ of the Horticultural and Agricultural Research Station, Long Ashton, Bristol, and the Horticultural Research Station, East Malling, Kent.

The Publication Committee welcome horticultural papers from all other sources.

2. All **manuscripts** should be in double-spaced typewriting, with a good margin, and should be addressed to the Editors, East Malling Research Station, near Maidstone, Kent, England. Papers must be written concisely. Historical reviews should be as short as possible and only such references to literature as bear directly on the subject should be included. Tables and illustrations, if any, must be only such as are absolutely essential for clear presentation.

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4. Each paper must conclude with a concise and critically correct **summary** of its actual content. It should contain any new or verified constants as well as any other critical data of permanent value but not tables or graphs. Any organism mentioned should be given its scientific name.

5. Where a paper is of a highly technical nature it should be preceded by a brief **synopsis**, in which its contents are simply and clearly stated for the benefit of non-technical readers.

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7. The **scientific names** given in the "List of Common British Plant Diseases", published by the British Mycological Society (Cambridge University Press, 1944) and "Common Names of British Insect and other Pests", published by the Association of Applied Biologists (The Mendip Press Ltd., Bath, 1947) must be employed.

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